Vol. 5. No. 1. March, 1948.

THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

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PUBLISHED QUARTERLY

By the Queensland Department of Agriculture and Stock, Brisbane

Issued by Direction of Hon. H. H. COLLINS,
Secretary for Agriculture and Stock.

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VOL. 5. NO. 1.

MARCH, 1948

AXILLARY GALL OF QUEENSLAND MAPLE.

By H. E. YOUNG, D.Sc.Agr., Pathologist, Science Branch, Division of Plant Industry.

SUMMARY.

The occurrence, morphology and previous observations concerning axillary gall of Flindersia brayleyana are discussed, and investigations described which showed that the disease is caused by a bacterium closely allied to Xanthomonas tumefaciens.

INTRODUCTION.

Queensland maple (*Flindersia brayleyana* F.v.M.) is a characteristic tree of the northern Queensland rain-forests and is of considerable importance as a producer of cabinet and general-purpose timbers. Plantations of this species have been established on cutover areas of the Atherton Tableland by the Queensland Forest Service and for many years large numbers of plants were normally raised each year in the northern Queensland forest nurseries for planting-out purposes.

In 1927, two seedling plants in the Gadgarra nursery on the Atherton Tableland were noted with gall-like growths in the axils of the leaves. This condition subsequently developed in all buds and the plants became stunted and eventually died. In 1928, the damage amounted to 3 per cent. of all seedlings; in 1930, 25 per cent. of the 55,000 plants raised were attacked and actual losses due to axillary gall amounted to 13 per cent. In the next year losses amounted to almost 50 per cent. of the stock produced, and high percentages of affected plants have appeared in subsequent seasons.

Some investigations were carried out at this time, when it was thought from the high population of jassids and thrips present that the trouble was

probably due to insect damage. However, no conclusive results were obtained. Isolations of organisms from gall tissue were made and a number of non-specific fungi and bacteria were obtained.

Work carried out concurrently in the area by J. Harold Smith (Entomologist) demonstrated that seed sown in insect-proof enclosures produced seedlings with just as high a percentage of affected plants as plants in unenclosed

Plate 1.
Plantation of *Flindersia brayleyana* affected by axillary gall.

seed-beds and thus showed that the effect was not due to the jassids and thrips which were suspected of causing the trouble. Insecticidal dusts and sprays were also used about this time but without effect on gall incidence.

In 1937 the author found gall damage in plantation trees and in naturally occurring trees of all ages in the virgin rain-forest. The damage caused to the plantation trees resulted in death of leading shoots and consequent development of numerous secondary leaders, causing a bunched and stag-headed appearance and reduced growth (Plate 1). The new buds also showed evidence

of stimulation and subsequent gall development. No galled plants had been put out in the plantations from the nursery. Seedling plants exhibiting gall symptoms were obtained for further investigation in Brisbane.

APPEARANCE OF DISEASED PLANTS.

The development of the condition has been traced. In a Queensland maple seedling there are two elongate-cordate cotyledons oppositely placed; the true leaves are alternate, with the laminae 2–3 inches long and a petiole

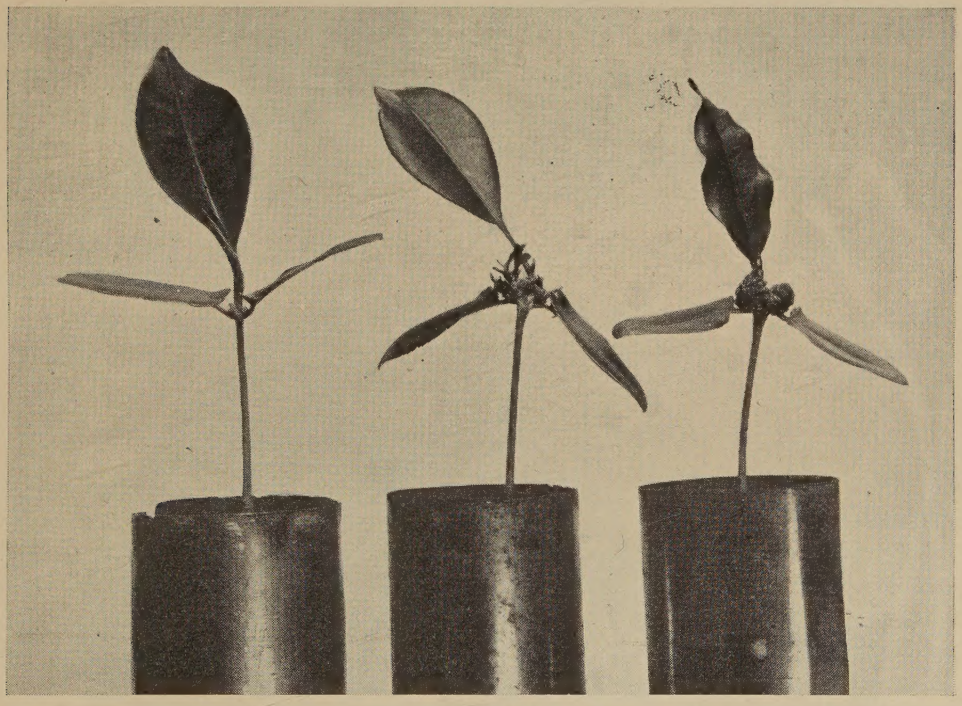

Plate 2.

Tubed seedlings of *Flindersia brayleyana* affected with varying stages of axillary gall.

$\frac{1}{2}$-inch long; the nodes are $\frac{1}{4}$–$\frac{1}{2}$-inch apart. In a normal healthy seedling the growth is confined to the terminal shoot. The first symptom of the trouble is the appearance of a small bud in the axil of a cotyledon.

In the case of an affected plant the axillary buds swell and the axil of the leaf is filled with swollen nodular tissue. Later a number of abortive shoots appear on the surface of the tumour; one or two of these may be almost normal in appearance so that instead of one growing point there may be several in each leaf axil. The growth of the terminal growing point is retarded and the plant becomes dwarfed and crooked. In severe cases of gall the stem

Plate 3.

T.S. through two oppositely placed axillary galls of *Flindersia brayleyana*. × 10.

Plate 4.

Aborted growing point of *Flindersia brayleyana* seedling affected by axillary gall. × 10.

is devoid of leaves and carries a gall up to 1 inch in diameter. After this stage is reached the plant soon dies, and in many cases death occurs before such severe malformation takes place.

It is common for galls to appear in more than one leaf axil; their usual size is $\frac{1}{4}$–$\frac{1}{2}$-inch in diameter. Typical naturally-affected maple seedlings exhibiting gall development are shown in Plate 2.

MORPHOLOGY OF THE GALLS.

The gall consists of an irregular proliferation of the axillary bud. In section it is seen to consist largely of parenchymatous tissue intersected by a number of vascular bundles each of which contains a few lightly lignified elements. A few layers of cork cells line the periphery. The vascular bundles terminate at growing points which are situated at the base of deep hairy depressions in the gall surface. Lateral division of the tumour cells apparently exceeds longitudinal division. A transverse section through two oppositely placed axillary galls is shown in Plate 3. Detailed structure of an affected growing point is shown in Plate 4.

Preliminary microscopic examination failed to reveal any pathogen. Necrotic areas were visible in some cases around what were presumably punctures caused by insects.

ISOLATIONS FROM GALL TISSUE.

Attempts to obtain cultures of organisms from the tissues resulted in the production of numerous colonies of fungi and bacteria. All organisms occurring with any degree of consistency were inoculated into healthy plants, but with negative results. The wide variety of organisms obtained in cultures was presumed to be connected with the difficulty in sterilizing the surfaces of the gall due to its irregular shape and deep depressions and the presence of insect punctures.

FURTHER INVESTIGATIONS.

Because of the negative results obtained from isolations and the similarity of the growth to the soft type of crown gall caused by *Xanthomonas tumefaciens*, more searching microscopic examination of the tumours was made.

Galls were impregnated with silver (Bielschowski's silver nitrate method) and sectioned. The sections were counterstained with eosin. Microscopic examination revealed rods, Y forms and branched forms (Smith, 1912). The bodies found usually occurred inside the tumour cells at the juncture of normal and tumour tissue and appeared to be distinct from the mitochondria. The cells containing the bodies occurred in small groups. Microscopically the appearance suggested a similar new growth to that evidenced by crown gall.

Further isolations were then made. In these cases, however, the galls were first sterilized externally with 1:1,000 mercuric chloride solution, washed in sterile water, and cut with a sterile scalpel. Small pieces of tissue were removed from near the proximal areas of the abnormal growth, macerated in sterile water, and dextrose agar plates poured with the maceration.

In a number of cases whitish bacterial colonies were obtained as well as various other bacteria and fungi. The white colonies grew vigorously on potato dextrose agar plates and slopes.

Microscopically the organisms forming the white colonies were shown to be Gram-negative bacteria, motile, with one polar flagellum, and measuring 0·6 to 0·85 $\times$ 2·5 to 3μ.

At the same time and in the same way isolations were made from crown gall of the peach. The organisms obtained were similar to those isolated from maple gall.

Cultures of both organisms were used as inoculum for nasturtium (*Tropaeolum*), Bryophyllum and laboratory-grown maple seedlings. All seedlings were grown from sterilized seed under glasshouse conditions.

The inoculations were carried out by smearing buds with a pure culture of the organism being used and pricking the plants through the smear. In other cases the organisms were introduced as suspensions by means of a hypodermic syringe.

Five days after inoculation with the *Xanthomonas tumefaciens* the nasturtium plants showed signs of tumour growth, by developing swelling at the points of inoculation.

Twelve days after inoculation gall formation was evident on two of the maple plants inoculated with the crown-gall organism.

On the same day one nasturtium plant inoculated with the maple gall organism showed signs of gall formation and three days later nine of the 25 seedlings inoculated with this organism exhibited the initial symptoms of maple gall at the site of inoculation.

Check inoculations using only sterile water caused no gall appearance except in one or two cases where a swelling due to wound callus appeared but did not develop any further.

The artificially induced galls on all the maple seedlings, whether of crown gall or maple origin, developed as typical maple galls and sectioning of the tissues showed a similar picture to that appearing in normally occurring maple gall.

In the case of both organisms the galls on nasturtium grew into similar soft gall structures.

Isolations from the artificially induced galls produced by inoculating maple seedlings and nasturtium seedlings with the maple gall bacterium were successful in demonstrating the presence of the organism used in the inoculum.

The maple gall organism was also used to inoculate axillary buds of aseptically grown mandarin seedlings in the glasshouse, and axillary galls were produced on two of the 12 seedlings used (Plate 5).

Plate 5.
Mandarin seedling artificially infected with axillary gall organism.

METHOD OF INFECTION.

No definite information concerning the method of natural infection which occurs has been obtained but there are indications that the trouble is soil-borne. As mentioned above, insect-proofing of seed-beds has not prevented the occurrence of the disease and its close affinity with the genuine crown-gall organism points to the soil as its source.

When the trouble was prevalent at Gadgarra, no occurrences were observed at the Wongabel nursery, a few miles distant. Gadgarra is a natural maple locality; the Wongabel area is not. It was observed on another occasion that where soil imported from a maple-bearing area was used as a seed cover a very high incidence of gall formation occurred in the treated beds as compared with other beds.

Experiments involving soil sterilization were laid down at the Gadgarra nursery in two separate seasons, but in each case the trials were vitiated by the occurrence of flooding due to the advent of the rainy season which occurs about seed germination time. No further observations have been carried out pending the resumption of production of maple plantation stock.

CONCLUSION.

It is considered that the investigations here described have successfully demonstrated that axillary gall of Queensland maple is due to infection by a species of *Xanthomonas* closely allied to *X. tumefaciens*.

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BERGEY *et al.* 1939. Manual of Determinative Bacteriology. Fifth edition. London: Bailliere, Tindall and Cox.

SMITH, Erwin F. 1912. The structure and development of crown gall. U.S.D.A. Bull. 255.

HENDERSONULA AGATHI n.sp., THE CAUSE OF LEAF CAST OF KAURI PINE IN QUEENSLAND.

By H. E. YOUNG, D.Sc.Agr., Pathologist, Science Branch, Division of Plant Industry.

SUMMARY.

"Leaf cast" disease of kauri pine is described and shown to be caused by a sphaeropsid fungus which has a Torula stage.

The fungus is compared with Hendersonula toruloidea and shown to be a different species.

The name Hendersonula agathi is proposed for the fungus and a diagnosis is given.

INTRODUCTION.

In 1936, kauri pine (*Agathis palmerstoni* F.v.M.) in forest nurseries and plantations in northern Queensland was found to be affected by a fungous disease which caused injury to the leaves and twigs and resulted in severe defoliation, as shown in the accompanying plate.

Bordeaux mixture (4–4–40) was used as a fungicide in the nurseries and complete control of the disease was established. In plantations control is uneconomical and in any case the disease causes severe injury there only in isolated areas where kauri pine grows weakly because of unfavourable site factors. The same disease was observed causing unimportant injury on naturally occurring *A. palmerstoni* in rain-forest in northern Queensland. The disease was later found on indigenous *Agathis robusta* C. Moore in southern Queensland and has appeared on nursery stock of this species with sufficient severity to warrant the application of control measures. It has also been observed on the same species of kauri pine in plantations. Isolations of the same fungus have been made from similar lesions on *Agathis australis* Salisb. in southern Queensland.

The disease is first manifested by a necrosis and wilting of the leaves, which eventually die and are shed. The leaves are marked by progressively enlarging necrotic areas with well defined edges. The lesions may eventually cover the whole leaf or may in less severe cases be restricted to irregular patches on the leaves. In very severe cases the twigs and smaller branches are also affected and wilt and die.

Black pycnidia occur on the upper surfaces of dead leaf tissue and also on the bark of twigs affected by the disease. On the diseased twigs elongate-oval "blisters" with longitudinal fissures are sometimes found. The blister cavity is filled with black thallospores.

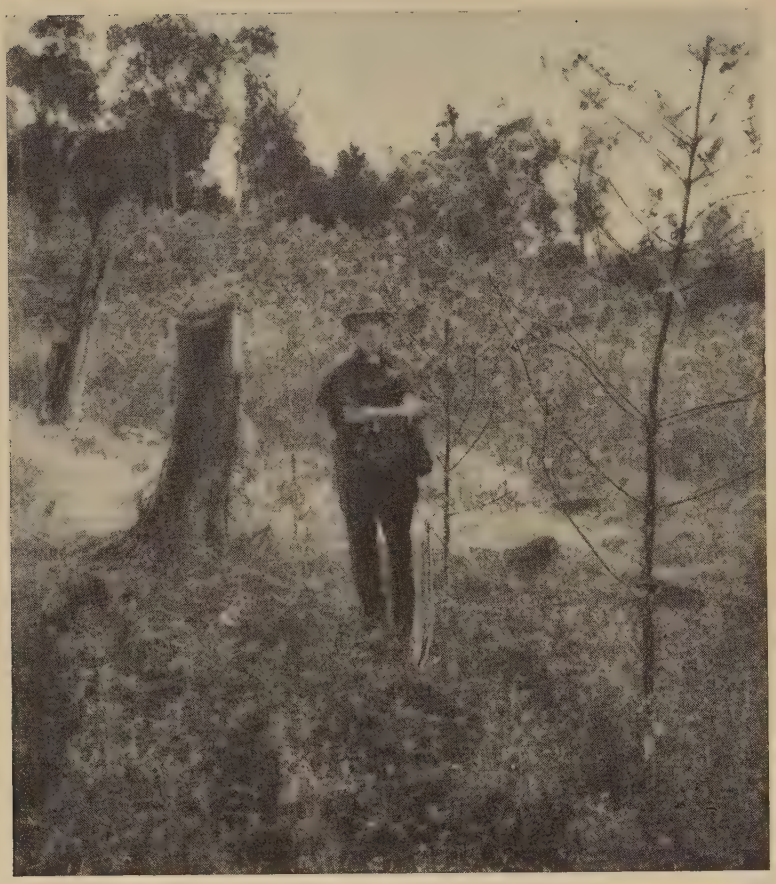

Plate 1.

Agathis palmerstoni affected with leaf-cast disease in a northern Queensland plantation.

CAUSE OF THE DISEASE.

Isolations from affected tissues and cultures from spores obtained from the pycnidia and blisters in all cases yielded a dark hyphomycete which in culture on kauri pine tissue formed typical pycnidia. Inoculations of potted plants of *Agathis robusta* in the glasshouse with pure cultures of the organism resulted in typical leaf-cast disease and the same fungus was isolated from the affected tissues.

DESCRIPTION OF CAUSAL FUNGUS.

In culture on potato dextrose agar the fungus grows readily and forms a white woolly mat which after several days changes colour to a dark olive green and eventually becomes olive black. No pycnidia were developed on agar media.

On sections of sterile kauri pine branches in tubes the fungus grows profusely over the surface and in three months pycnidia develop partly immersed in mycelial aggregates on the surface of the bark.

The pycnidia occur singly, are spherical in shape and about 300μ in diameter with a short ostiole. Sometimes the pycnidia are irregularly shaped and may be laterally compressed.

In the pycnidia all the spores are hyaline and measure 13 to 18 $\times$ 5 to 6μ. After extrusion the majority are three-celled and measure 13 to 20 $\times$ 6 to 8μ; the central cell is brown and the end cells hyaline. Occasionally the spores are four-celled with two central brown cells, and very occasionally all cells of the three-celled spores are uniformly brown. The various spore types are shown in the accompanying figure.

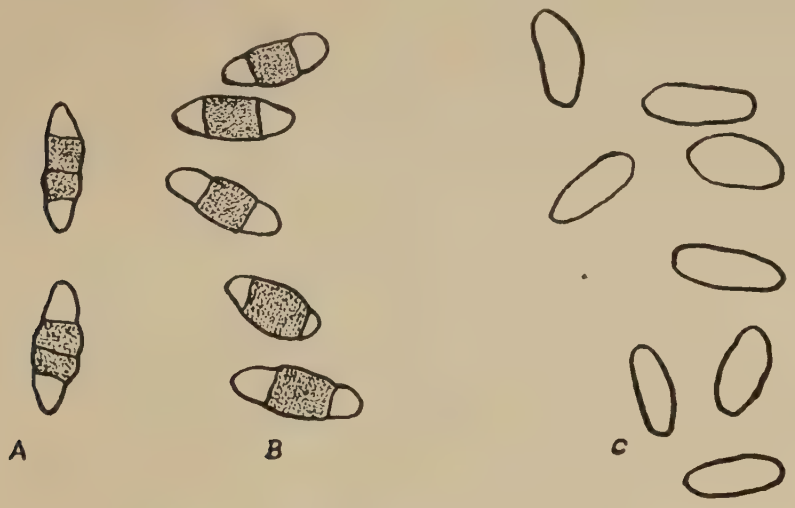

Figure 1.

Tracing of projection of pycnospores of *Hendersonula agathi* n.sp. A, 4-celled extruded spores; B, 3-celled extruded spores; C, 1-celled hyaline non-extruded spores.

TORULA STAGE.

In addition to pycnospores the fungus sometimes produces chains of thallospores in fruiting bodies on diseased twigs. Pure cultures obtained from thallospore isolations gave rise to the same fungus as do pycnospore cultures and inoculations of kauri pine with the thallospore isolations cause typical leaf-cast disease. No thallospores were produced in pure culture.

The thallospores measure 3·5μ in diameter, and may be globose to oblong, measuring 8 $\times$ 3·5μ. Uniseptate forms of the latter shape are sometimes seen. The thallospores are at first hyaline and become dark brown with age.

SYSTEMATIC POSITION OF THE FUNGUS.

Only one pycnidial fungus whose spores are hyaline and non-septate in the pycnidium and become two-septate on extrusion with the middle cell brown has been previously recorded. This was described under the name of *Hendersonula toruloidea* Nattrass (Trans. Brit. Mycol. Soc., XVIII, p. 197,

1933; Rev. Appl. Mycol. XIII, p. 382, 1933). This was isolated from stone-fruit trees and apple trees and was shown to be associated with dieback and gummosis of the former. It was also recorded from the orange in Rhodesia. The same fungus was later recorded (Nattrass, Rev. Appl. Mycol., XIV, p. 83, 1935) from lemon trees in Cyprus associated with gummosis, and also from mature *Populus nigra* trees which had died. It was also found on figs and walnuts.

The present fungus is not *Hendersonula toruloidea,* as a comparison of the salient characters of the two fungi shows (see Table 1), but must be referred to the same genus.

Table 1.

Comparison of Characters of Hendersonula toruloidea and Hendersonula n. sp.

——	*H. toruloidea.*	*H.* n. sp.
Pycnidia	120–195μ	300μ
Hyaline pycnospores	10·5–14 x 4·5–5·5μ	13–18 x 5–6μ
Extruded pycnospores	12–13·5 x 4–5·5μ	13–20 x 6–8μ
Extruded pycnospores	3–celled	3–celled, sometimes 4–celled
Extruded pycnospores	Middle cell brown	Middle cell brown or 3 cells brown ; 2 middle cells brown in 4–celled form
Stromata	Eventually compound	Uniloculate
Thallospores	10 x 4μ	8 x 3·5μ

The fungus causing leaf-cast disease of kauri pine is proposed as a new species of the genus Hendersonula with the following diagnosis.

Hendersonula agathi sp. nov.

Stromatibus solitariis, immersis vel erumpentibus, unilocularibus, nigris. Loculis immersis vel protuberantibus, globosis vel e latere compressus vel irregularibus. Sporophoris hyalinis, teretibus, totos loculos vestientibus, o-septatis. Pycnosporis oblongis vel ovalibus, primo hyalinis, o-septatis 13–18 $\times$ 5–6 μ: dein saepe 2-septatis, fusco centrali cellulo praeditis, interdum fusco omnibus 13–20 x 6–8μ subinde 3-septatis, fuscis centralibus cellulis. Hyphis primo hyalinis, septatis, ramosis, in moniliformes, globosus (3–5μ dia.) vel oblongus (8 $\times$ 3·5μ), vel cuneatus, fuscus o-vel rariter 1-septatis thallosporas, secedentibus.

ACKNOWLEDGEMENTS.

The assistance of Mr. E. W. Mason, M.A., M.Sc., Mycologist, Imperial Mycological Institute, in the identification of the fungus concerned is gratefully acknowledged.

RHIZOCTONIA ROOT ROT OF HOOP PINE.

By H. E. YOUNG, D.Sc.Agr., Pathologist, Science Branch, Division of Plant Industry.

SUMMARY.

An outbreak of root rot of Araucaria cunninghamii Ait. in a forest nursery and an experiment aimed at its control are described and the nature of the causal organism is discussed. Inoculation trials with pure cultures of this organism are reported upon.

INTRODUCTION.

During April, 1935, a number of plants of hoop pine (*Araucaria cunninghamii*) were reported to be dying in the forest nursery at Googa in the Brisbane Valley, southern Queensland. The plants were two-year-old nursery stock planted in drills and the trouble at the time was confined to one nursery bed.

On inspection is was seen that the bark below the ground level on affected plants was in various stages of decay. The bark became loose and the tissues brown as far in as the cambium. In cases where infection was older, the bark stripped off the roots as the plants were removed from the ground. Plants were found which exhibited no above-ground symptoms of wilting, but which had a well-developed rot of the root system. It is quite common, however, for young hoop-pine plants to appear quite healthy above ground for some weeks after severe injury has occurred to the root system, such as that occasioned by root-pruning operations or by the attack of Scarabaeid larvae.

The trouble appeared first at one end of the bed and then began to spread along the bed. However, when examination revealed the presence of abundant fungus sclerotia on the surface of the injured tissue and many ramifying hyphae, suggesting the presence of a species of Rhizoctonia, preventive measures were immediately undertaken, and the nursery beds and paths were thoroughly treated with Cheshunt mixture, after which there was no further spread. A small outbreak was again experienced one year later, but a similar treatment effectively checked it.

In the same district, several dead plantation trees which had been put out from the nursery two years before exhibited the same symptoms as trees found affected in the nursery.

The same fungus was found on nursery plants at Kalpowar and Kilkivan in southern Queensland and at Atherton in northern Queensland. At Yarraman (southern Queensland) several deaths following transplanting from the seedling beds (at 12 months of age) into drills in the transplant beds were found to be associated with the same fungus. The greatest losses (up to 10 per cent.) occurred at Kilkivan where, at the Brooyar nursery, infection appeared in transplants which had been moved four months previously.

CAUSAL ORGANISM.

The infected roots of the plants show the superficial strands and hyphae of the fungus, which are brownish in colour. Infection cushions and black sclerotia are present and these appear to be produced by the internal hyphae

beneath the periderm. The sclerotia are small, being approximately 300μ in diameter. Specimens and cultures were forwarded to the Imperial Mycological Institute for identification. The Institute reported that the fungus was a strain of *Rhizoctonia crocorum* (Pres.) D.C. group. It is similar to an isolation sent there some years ago by Professor H. R. Briton-Jones from cotton roots in Trinidad, and very similar to specimens of a corticial root rot of tea seedlings forwarded to the same place by Mr. R. Leach from Nyasaland, where the fungus was the cause of considerable loss. It has also been recorded by the Institute on cotton roots from Tanganyika Territory.

Buddin and Wakefield (Rev. Appl. Mycol. VI, p. 756; VIII, p. 527, &c.) have shown that the perfect form of the western European strains is *Helicobasidium purpureum* (Tul.) Pat. The perfect form of the tropical strains on cotton and on tea in Nyasaland, according to the report by the Imperial Mycological Institute, is unknown, but Miss Wakefield found *H. compactum* Boedijn on specimens from South Africa. The species was originally described from Java (Rev. Appl. Mycol. IX, p. 562).

Specimens of a felty fungus occurring at and just above ground level were found in the Brisbane Valley in southern Queensland and at Banyabba in New South Wales. The fungus, in all cases save one in the Brisbane Valley, was growing on hoop pine. In the odd case it was on *Lantana camara*. Specimens of the fungus were forwarded to Dr. J. N. Couch of the University of North Carolina, who was working with the allied group *Septobasidium*. Couch reported that all the specimens were very like *H. compactum* but were not in fruit.

A subsequent specimen collected on hoop pine in the Brisbane Valley was a fertile one and agreed with the description of *Helicobasidium compactum*. This is of interest, as it is probable that this is the perfect stage of the causative organism of root rot in hoop-pine plants as described above.

The fungus *Rhizoctonia crocorum* was isolated in pure culture and 2-year-old hoop-pine plants were inoculated with the isolations. Inoculation was carried out just below ground level by wounding the cortex of the main root with a scalpel and applying some mycelium from the isolation in question. In other cases roots of naturally infected diseased plants were placed in the soil around the experimental plant. In some instances the plant was wounded and in others it was left intact.

In no case did any of the inoculated plants die, but on examining their root systems it was found that a number of the plants had been typically affected with the root rot but that they had survived long enough to produce new roots from near the soil surface and had lived on. This was probably due to the fact that in the glasshouse conditions under which the inoculations were carried out a high humidity prevailed. This disease after the preliminary attack apparently did not cause further damage in these experimental cases. This phenomenon would appear to be the same as that observed in the Brooyar nursery trial (see Table 2).

CONTROL.

Rhizoctonia root rot has not become of any major importance in Queensland forest nurseries because it is easy to control. In infected nurseries Cheshunt treatment has proved successful in routine operations, the procedure being to treat the beds which are observed to carry any infection and also the new beds prepared for the reception of any transplants.

Observation plots were laid out in the affected beds of the Brooyar nursery. The treatment applied was Cheshunt mixture at the rate of one gallon per square yard. The fungicide was prepared by thoroughly grinding together 2 oz. powdered copper sulphate and 11 oz. ammonium carbonate, mixing well, and storing in stoppered glass containers for 24 hours before use. For application 1 oz. of the mixture was dissolved in 2 gallons of water.

The results of the observations carried out at the Brooyar nursery are shown in Tables 1, 2, and 3. In these tables, plots 1 and 3 were treated with Cheshunt (normal mixture) whilst plots 2 and 4 were left untreated as checks. Treatment was carried out in February; the first observation was made four months later and the second seven months from time of treatment.

Table 1.

First Observation of Cheshunt Treatment Trial. Four Months after Treatment.

Plot.	Treatment.	No. of Healthy Plants.	No. of Affected Plants.
1	Cheshunt	310	36
2	Check	249	68
3	Cheshunt	344	25
4	Check	331	54
Total	Cheshunt	654	61
	Check	580	122

Table 2.

Second Observation of Cheshunt Treatment Trial. Seven Months after Treatment.

Plot.	Treatment.	No. of Healthy Plants.	No. of Affected Plants.
1	Cheshunt	313	33
2	Check	264	53
3	Cheshunt	343	22
4	Check	325	55
Total	Cheshunt	656	55
	Check	589	108

The discrepancies between the counts for total numbers of Tables 1 and 2 are due to the inclusion or exclusion of plants on the border of the plots. The proportion of diseased to healthy plants in the treated plots as shown by

the two tables indicates that there was no further development of the trouble following the first observation.

At the commencement of the experiment all obviously affected plants were removed from the plots, but examination showed that a number of plants which were still healthy in appearance above ground were badly affected below. These plants probably would have died whether treated or not, since they were already infected before treatment. This would explain most of the deaths which occurred in the treated plots as shown in the tables, and if allowance is made on the basis of this reasoning by eliminating these plants at the commencement of the experiment the final figures for the observations would be approximately as shown in Table 3.

Table 3.

RESULTS OF CHESHUNT TREATMENT ON RHIZOCTONIA ROOT ROT, WITH CORRECTION FOR PLANTS AFFECTED PRIOR TO TREATMENT.

Period.	Treatment.	No. of Healthy Plants.	No. of Affected Plants.
First Observation	Cheshunt	654	0
	Check	580	68
Second Observation	Cheshunt	656	0
	Check	589	59

The figures indicate that the treatment prevented the loss of nearly 10 per cent. of the plants in the beds.

The experiment indicated that Cheshunt mixture is of value for controlling the disease. Results in routine treatments have borne this out. No foliage injury has been found associated with the treatment. The use of the fungicide at four times the normal strength has been shown to have no deleterious effect on the growth of hoop pine.

CONTRIBUTING FACTORS.

A number of plants were observed to have recovered from Rhizoctonia attack. These plants showed typical sclerotia on the surface of the roots but were making new root growth, indicating recovery. It was considered probable that the onset of the cooler winter weather in May would assist the plants in their resistance to the trouble. The disease is essentially one of summer occurrence; it has usually made its appearance during the early months of the year and so far has not been reported as initiating an attack during the winter. Whether infected plants which have withstood the attacks of the fungus during the winter would succumb during the following summer is unknown, but it is considered that this would happen in a number of cases.

The disease appears to affect weakened plants to some extent. This has been observed at the Yarraman nursery where, during one year, a considerable number of seedlings, which necessarily receive a certain amount of injury during lifting operations, died after transplanting at 12 months of age and were found to be infected with the fungus. In this nursery no deaths of established plants have been connected with the disease, though this has occurred in other localities.

THE USE OF VEGETATION IN LOCATING SOLONETZ SOILS IN QUEENSLAND.

By P. J. SKERMAN, B.A., M.Sc.Agr., Q.D.D., Agricultural Resources Officer, Bureau of Investigation, Department of Public Lands.

The use of vegetation in determining soil characteristics is often fraught with errors, but in reconnaissance survey work as is carried out by the Bureau of Investigation any correlation between soil type and the vegetation which it carries is valuable in making a preliminary assessment of the possible utilization of the land.

Plate 1.

"Sandalwood" (*Eremophila mitchelli*) country, Burdekin Valley.

"Sandalwood" as an Indicator.

Eremophila mitchelli has a wide distribution in Queensland. It is found from the western edge of the Darling Downs westwards to Thargomindah, and extends from the New South Wales border to the Norman River, in the Gulf of Carpentaria area. It reaches the coast at Rockhampton. It is known locally as "sandalwood," "false sandalwood," "rosewood," "sandalwood box," and "buddah," and is being used in place of the true sandalwood for shipment to the East. The tree usually grows to a height of 10–15 feet. It occurs as a consociation, typically in the form of isolated

thickets each one-half to one acre in area, or in extended association with broad-leaved box (*Eucalyptus populifolia*), brigalow (*Acacia harpophylla*), wilga (*Geijera parviflora*), or gidgea (*Acacia cambagei*). Its occurrence in a consociation is the subject of this note.

Hubble (1941), in his soil survey work for the Queensland Cotton Stimulation Committee, referred to the "sandalwood" area as follows:—"The presence of fairly thick sandalwood is usually regarded as indicating what are known in these areas as "spewy" soils . . Apparently this character is an expression of poor internal drainage on these soils. It is said that

Plate 2.

"Sandalwood" between channels of the Belyando River. Note claypan formations.

following heavy prolonged rain, spewy soils are so soft that stock walking on them sink in, causing the whitish sub-surface soil in a semi-liquid state to be squeezed up on to the surface." He also observed that sandalwood was shallow-rooted.

The typical soil profile on which sandalwood develops as a consociation consists of a surface horizon varying from 6 to 12 inches of a very fine sandy loam, overlying 1–3 inches of a bleached fine sandy loam somewhat cemented, and then a clay horizon often blocky in structure and somewhat mottled. Variations in this profile occur. The fine sandy loam is very powdery and often blows away under stocking to leave bare claypans.

The bleached horizon overlying the clay probably indicates some lateral leaching, and it is this horizon which is brought to the surface by the passage of cattle when the soil is waterlogged. The clay horizon is relatively impermeable to water, hence the "spewiness" of the waterlogged surface soil and the leaching of the A_2 horizon.

Plate 3.

Green "sandalwood" patch, Ward River, Charleville.

The impermeability of the clay horizon is due to the high percentage of sodium in the exchangeable cations. Cassidy (1944) has indicated that where the exchangeable sodium constitutes more than 15 per cent. of the total exchangeable cations adverse physical effects might be experienced in handling the soil for cultivation. Although it is as yet too early to dispute this figure, the behaviour of some of the soils in the field would indicate that even below this figure some adverse effect might be expected under irrigation.

These solonized patches are comparatively widespread throughout the habitat of " sandalwood " and occur usually on the outwash from hills or in the channels of or adjacent to inland streams, indicating that " cyclic " salt has accumulated as a result of drainage from higher lands. There is no connection in this case with rocks which are inherently charged with salt, e.g., the Walloon sandstones.

The following table gives the percentage of sodium in the total exchangeable cations from soils in various parts of Queensland, with particular reference to " sandalwood " areas:—

Location of Sample.	Depth.	Percentage of Na in Total Exchangeable Bases in " Sandalwood " Patch.	Highest Percentage of Na in Total Exchangeable Bases in Adjacent Soils not Growing " Sandalwood."
Theodore No. 10 type soil	4"–20"	13·0	9·0
Moura No. 7 type soil	6"–18"	11·4	5·9
Cunnamulla	0"–12"	13·7	8·7
Charleville, Ward River	0"– 6"	19·0	..
St. George, Balonne River	0"– 2"	21·0	5·0
Burdekin River near Kirknie Creek ..	4"–14"	22·0	.
Burdekin River near Kirknie Creek ..	30"–36"	44·0	..

Other areas where such patches occur, in which field texture tests indicate solonization, can be found within the channels of the Belyando River near Alpha; in the Gibber Gunyah area, near Theodore; and along the Macintyre River, in New South Wales.

Plate 4.

Bull-oak (*Casuarina leuhmanni*) country, Condamine Highway. Odd cypress (right) and box trees (left).

Where "sandalwood" occurs in a general mixed flora such as box, "sandalwood," wilga, &c., the soil analyses show that the soil sodium is not unusually high. Evidently these associated trees cannot compete when the soil sodium exceeds about 10 per cent.

Bull-oak as an Indicator.

Another interesting association is that provided by the bull-oak (*Casuarina leuhmanni*). A large stretch of this country occurs in the Dalby-Miles-Condamine triangle west of Wilkie Creek, in which bull-oak and cypress pine (*Callitris glauca*) alternate in dominance. The country has long been known as very poor to almost useless grazing land. A soil profile in a bull-oak patch and one in a bull-oak-cypress association showed the following interesting features:—

Location.	Depth.	Horizon.	Percentage of Total Exchangeable Bases.			Colour and Texture.
			Ca.	Mg.	Na.	
1 mile west of Columboola, near railway line.	0″– 3″	A_1	42·0	41·0	10·0	Grey-brown sandy loam.
	3″– 4″	A_2	24·0	50·0	22·0	Bleached grey sandy loam.
	4″–30″	B_1	9·0	41·0	48·0	Grey coarse sandy clay with yellow and reddish-brown mottling. Gritty.
	30″–48″	B_2	4·0	42·0	52·0	Bluish-grey clay with red and yellow mottling. Gritty and soapy when wet.
	48″–60″	B_2C	5·0	39·0	54·0	Grey clay with red mottling. Friable; soapy when wet.
Condamine Highway	0″– 8″	A	28·6	34·3	1·7	Sandy loam.
	8″–15″	B_1	5·2	85·0	7·6	Sandy clay. Gritty.
	15″–24″	B_2	3·0	87·0	8·7	Sandy clay, slightly mottled.

In the former case the calcium in the subsoil has been replaced by sodium, and in the latter by magnesium chiefly, with some rise also in the percentage of sodium.

Somewhat similar bull-oak country occurs in less extensive patches in the Burdekin Valley south of Scott's Creek, on the Ayr-Bowen road, in the Selma area west of Emerald, and in a number of other localities.

General.

Each of the above vegetation associations indicates soils generally too infertile for general agricultural and pastoral use, and unsuited to irrigation development by reason of poor drainage.

Acknowledgement.

It is desired to acknowledge the assistance of the Agricultural Chemist, Department of Agriculture and Stock, and his staff in carrying out the chemical and mechanical analyses on the above soils.

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IRRIGATION WATERS OF THE BUNDABERG AREA.

By NORMAN J. KING, Assistant Director, Bureau of Sugar Experiment Stations.

SUMMARY.

The underground irrigation water supplies of the Bundaberg area have been divided into three classes based on the overlying geologic formation. The topography and the soil characteristics of the two principal land types below which the main water-bearing beds are located are briefly discussed.

A number of waters from each of the three geologic areas have been analysed and their compositions compared, particularly on the basis of ionic ratios.

Tables of typical irrigation plant data are appended.

INTRODUCTION.

The very large and rapid extension of irrigation of sugar cane crops in the Bundaberg area since 1932 made a study of water quality in that district desirable. Water analyses performed during a period of over 40 years indicated wide extremes in mineral content, but no systematic study of the quality of the various water-bearing beds had been attempted prior to the work reported here.

The Bundaberg cane-growing area comprises five sugar mill districts with an average annual harvestable area of approximately 26,000 acres. The mill areas follow the basins of the Burnett, Elliott, and Kolan Rivers, with the major cane-producing areas concentrated within 20 miles of the sea coast. The soil types are sharply defined and are found to have an important bearing on the quality of the subterranean water. The Woongarra basaltic red loam has been longest cultivated and is the most important of the district's sugar cane soils. Next in importance is the reddish sandy forest type, while the recent alluvial soils of the Burnett and Kolan Rivers are third in area cultivated. A number of sub-types of lesser importance agriculturally have also been defined (King, 1935).

As early as 1906, Maxwell listed partial analyses of 194 waters from the Woongarra area in order of their content of total solids and salt (sodium chloride), but no reference was made to the relative amounts of the various ions present. At this period, following the 1901-03 drought, interest in irrigation was aroused, but such plants as were installed were not continued in operation. Most of the waters discussed by Maxwell were samples from wells not being used for irrigation, and there is nothing to indicate that they were representative of extensive water supplies.

The remarkable success in irrigating cane attained on large plantations at Bingera and Fairymead after the 1932 drought led to the rapid installation of a large number of individual irrigation plants throughout the

district, pumping in the main from subterranean supplies. By 1947 there was estimated to be 177 individually owned plants operating, of which 152 were pumping from underground supplies. The remaining 25 plants pumped from either the Burnett or the Kolan River.

Basaltic formations frequently yield valuable supplies of water to wells and boreholes, though where they are very thick the water table may lie at a great depth. Water boring results in basaltic areas in Transvaal (Dixey, 1931) showed that for a total of 258 bores, with a mean depth of 138 feet, the average depth of water was 90 feet, rising to 50 feet, and the average yield was 26,500 gallons per day. The water occurred in joint openings and in the zones of vesicular and fragmental material lying between successive lava flows. Between the flows there was frequently much soil and decomposed rock due to weathering of the earlier flow prior to the outpouring of the succeeding one. Owing to the numerous open joints, basalt takes in surface waters very readily. In the Woongarra formation, however, water for irrigation on a reasonable scale is not obtainable from the basalt despite the 100-feet thickness encountered at some locations. A flow of 26,500 gallons per day—as quoted above—would be quite inadequate for even small-scale sugar cane irrigation, this amount per hour being a normal requirement. Irrigation wells and bores which have been developed on this formation have invariably gone right through the basalt into the sandy and gravelly water-bearing drifts below, which are part of the fresh-water sediments of the Burrum series of Cretaceous age (Bryan and Massey, 1926).

The number of successful large-scale irrigation installations on this basaltic area is small, but indications are that more extensive water-bearing beds exist, though their exploitation may be costly. The largest individual plant is a 12-inch one, but in the same locality, around the Qunaba-Spring Hill section, several large plants have been operating successfully for over 10 years. This is the area from which most water is being pumped in the Woongarra, but isolated plants to the south, east, and west of The Hummock suggest that good water-bearing drifts exist in these sections also. In every case the large water supply is below the basalt, though extensive seepage through open joints is usually encountered when sinking wells. No doubt this percolation of water through varying thicknesses of igneous formation has an influence on the composition of the water, the higher calcium and magnesium content of the sub-basaltic waters conforming to what might be expected from a highly basic rock.

The sub-forest water supplies, particularly those of the South Kalkie-Alloway-Clayton belt, are much more uniform in depth and distribution. The topography of the country is generally flat, and the depth at which water is encountered is, allowing for surface inequalities and variation in water-table level at time of drilling, remarkably constant. There is little doubt that a water-bearing drift of considerable area underlies this section

of the Burrum series, as in more than 100 bores in this small cane-growing locality water-bearing material has been encountered at approximately a constant depth. The fact that ample supplies could not be pumped from some of the bores put down is not an indication of absence of a so-called "stream," but merely means that a section of drift with low permeability had been encountered. In any sedimentary formation the particle size of the sediments varies from point to point, and the rate of flow of water through the sediments varies accordingly. Examination of the "draw-down" figures in Table 8 shows that a high degree of freedom exists in these sub-forest drifts, since the water level sinks only 1 to 4 feet in most cases with a pump output of up to 65,000 gallons per hour. The capacity of this water-bearing bed was shown during the severe drought of 1946, when the demand on irrigation plants was at least double that of a normal year. The static water level fell, on an average, 5 or 6 feet throughout the area, but as there is an average of 30 feet depth of water-bearing drift this fall was not considered a serious one in terms of depletion of water supply.

The sub-alluvial water supplies have, with the exception of the large-scale installations on Fairymead Plantation, received less attention than those in the Woongarra and forest areas. During drought periods, however, a considerable number of bores have been sunk with varying degrees of success. On the Burnett River no uniformity in depth or type of water-bearing material has been experienced, and this is in line with general knowledge of other recent alluvial deposits. Layers of silty or clayey material at different depths divide the water-bearing strata and no unbroken gravel layers of considerable depth appear to have been encountered. The presence of clay seams restricts water flow into the spears and reduces the body of water available. There is also evidence of direct communication with the tidal waters of the Burnett River, as discussed under water quality. Rather similar conditions obtain on the Kolan River, though the attempted development of irrigation there has been less extensive.

The Burnett River supplies a considerable volume of irrigation water for cane-growing in the Bingera and adjacent areas. The weiring of this stream in 1934 impounded a large quantity of good quality water for this purpose. Bingera Plantation and a considerable number of individual farmers pump from the river throughout the drier months of the year, and so extensive is the Burnett River catchment area that even during the 1946 drought the water level did not shrink to a dangerous point. Below the weir the river is tidal and no water is pumped for irrigation. Several small or medium-sized pumps operate on the Kolan River, which is not weired, but all are above the limit of tidal influence.

The data discussed in this paper were obtained principally during 1946, when pumping was at its maximum and when quality might be expected to be at its worst. Many of the waters were subjected only to partial analysis, but a complete analysis was made of a true cross section of the various water

types. Methods used were, with minor variation, those described by Cassidy (1944), except that potassium was determined by the cobalti-nitrite method of Piper (1942).

WATER QUALITY.

The composition and the quality of ground waters vary greatly from place to place and often within short distances. The variations are due to differences in the chemical composition of the rocks through which the waters have percolated, to the type of underground circulation, and to the period of contact with rocks and soils. In comparing the sub-basalt and sub-forest

Table 1 (a).

SUB-BASALTIC WATERS BEING USED FOR IRRIGATION.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
1	J. Lutz, Sandhills Road	102·3	4·2	52·8	..
2	G. Fabricato, Springfield Road	3·3	1·9	2·1	..
3	Sugar Experiment Station	3·3	5·6	4·2	1·4
4	J. Chappell, Burnett Heads	8·2	9·6	1·8	7·8
5	Qunaba Irrigation	29·5	11·9	15·1	..
6	Qunaba Mill Supply..	88·8	..	49·7	..
7	Qunaba Mill Supply..	78·5	13·7	43·2	..
8	R. G. Strathdee, Burnett Heads	44·2	13·9	24·5	..
9	W. J. Zunker, Qunaba	13·9	12·6	8·2	4·4
10	F. Zielke, Ashfield Road	72·1	7·2	29·2	..
11	Jorgensen Bros., Burnett Heads	28·6	10·2	19·3	..
12	Spring Hill Plantation	35·6	10·9	19·6	..
13	W. C. Stockwell, Springfield	22·4	1·9	7·7	..
14	W. Slane, Qunaba	17·6	10·7	10·7	..
15	T. Young, Burnett Heads	19·4	9·8	14·0	..
16	R. M. Hurley, Sandhills Road	17·1	11·0	12·2	..
17	H. S. Skyring, Wawoon	9·9	1·9	3·9	..
18	G. C. C. Maughan, Gahan's Road	86·2	3·2	49·0	..
19	A. W. Bates, South Kolan	26·5	3·0	1·9	1·1
20	J. C. Maughan, Seaview Road	231	13·7	36·6	..

waters in the Bundaberg district, the differences in quality are very apparent. The former type, because of their location below a thick basalt layer, would be expected to be adulterated by percolating water which, during its passage through cracks and fissures in the rock, leaches out soluble mineral material. The relatively high Ca, Mg, Na, K, Cl SO_4 and HCO_3 content is suggestive of such contamination. By contrast the sub-forest waters are low in mineral matter, the overlying 30 or 40 feet of sandy sediments contributing little soluble mineral material under the influence of leaching. This overlying soil is known to be deficient in soluble bases and has, in fact, to be periodically limed to correct the undesirable concentration of hydrogen ions which develops under natural conditions.

The sub-alluvial waters being used for irrigation are too few for comparison with the other types, but the large number which have been found unsuitable for irrigation indicates contamination with tidal river waters.

The partial analysis figures given in Table 1 (a) indicate the composition of the waters being pumped from drift beds below the Woongarra and Hill End basaltic formations, while Table 1 (b) contains similar figures for waters in the same areas not yet being pumped extensively. The data given in these tables suggest that the waters are not of good quality, though, as will be mentioned later, total salt and chloride content is not the best criterion of water quality. Sodium chloride, calculated from chlorine, averages about 50

Table 1 (b).

SUB-BASALTIC WATERS NOT BEING EXTENSIVELY PUMPED.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
21	A. R. Greenshill, Windermere Road ..	44·0	17·2	35·4	..
22	A. C. Zischke, St. John's Road	16·4	7·9	12·9	..
23	B. Dargusch, Cattermull Avenue	36·0	17·5	27·3	..
24	T. W. Sharp, Barolin	12·2	1·6	5·3	..
25	T. W. Sharp, Barolin	54·8	11·2	32·2	..
26	W. H. Wessel, Seaview Road	113	25·9	66·2	..
27	R. Volzke, Rubyanna Road	104	14·0	57·0	..
28	C. Braddock Pemberton	5·7	9·6	4·2	..
29	C. Wittkopp, Sandhills Road	115·5	6·5	66·9	..
30	E. Galea, Springfield	24·9	15·2	26·8	..
31	G. Mangano, Barolin Road..	93·3	9·3	33·6	..
32	F. Faulkner, Burnett Heads	58·4	15·4	34·0	..
33	K. Young, Qunaba	102·8	14·9	30·6	..
34	K. Young, Qunaba	89·0	15·2	25·7	..
35	J. Donovan, Sandhills Road	60·0	14·9	41·1	..
36	K. Rasmussen, Hummock	12·7	9·8	3·7	6·1
37	H. J. Strathdee, Burnett Heads	35·8	21·7	13·5	..
38	G. H. Baldry, Burnett Heads	53·1	12·9	33·0	..
39	H. Killer, Sandhills Road	39·3	21·9	24·7	..

grains per gallon and attains well over 100 in some areas. The water of highest salt content—viz., 231 grains per gallon—is being used for irrigating cane, but it is too early to say whether any ill-effects will follow its continued use. The small proportion of these waters carrying free alkali is characteristic of the subterranean supplies of the district.

Table 2 gives partial analyses of 37 waters from the drift beds underlying the sandy loam forest lands of the district. These lands are farmed intensively in South Kalkie, Alloway, Oakwood, and Gooburrum, and it is in these areas that irrigation has advanced more than elsewhere. The waters are very low in both monovalent and divalent ions and on this basis can be regarded as of very high quality. The very low alkalinity indicated in the

majority of these waters is probably only a measure of the amount of acid required to discharge the alkaline colour of the methyl orange. Boiling with phenolphthalein for a considerable period does not develop any pink coloration and indicates the absence of bicarbonates of calcium and magnesium.

The underground waters of the alluvial lands on the Burnett and Kolan rivers are shown by Table 3 to have a much higher salt content and alkalinity than those under the basaltic and forest lands. All of these waters are from

Table 2.

SUB-FOREST WATERS BEING USED FOR IRRIGATION.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
40	J. T. Thiele, South Kalkie	2·5	0·5	1·2	..
41	S. Vecchio, South Kalkie	2·5	0·4	0·7	..
42	H. Petterson, South Kalkie	3·3	0·4	0·7	..
43	V. Parisi, South Kalkie	7·62	0·5	0·9	..
44	H. Rehbein, South Kalkie	8·5	0·4	1·9	..
45	G. Marano, South Kalkie	6·2	0·4	1·2	..
46	W. T. Hopkins, South Kalkie	3·9	0·2	1·2	..
47	P. F. Plath, South Kalkie	3·2	0·2	1·6	..
48	R. Lerch, South Kalkie	4·2	0·7	0·5	0·2
49	C. E. Tesch, South Kalkie	2·5	0·4	0·7	..
50	W. Truscott, South Kalkie	2·5	0·4	0·7	..
51	W. Truscott, South Kalkie	3·3	0·4	1·1	..
52	F. Jacobsen, South Kalkie	9·2	0·2	0·7	..
53	H. Gollschewsky, South Kalkie	1·9	0·4	1·4	..
54	A. Courtice, South Kalkie	5·3	0·5	1·8	..
55	F. J. Walk, South Kalkie	10·4	0·2	2·3	..
56	H. Lerch, South Kalkie	10·2	1·1	2·3	..
57	S. Marano, South Kalkie	7·2	0·4	2·3	..
58	Thiele Bros., Alloway	4·9	0·9	1·6	..
59	W. Douglas, Alloway	4·4	0·7	0·5	0·2
60	B. Anderson, Alloway	4·4	0·9	0·7	0·2
61	H. D. Buss, Maryborough Road	5·6	1·1	1·6	..
62	G. Torrisi, Kepnock	4·9	0·4	1·4	..
63	L. Kent, Kepnock	5·8	0·5	2·3	..
64	A. F. Lutz, Clayton	9·9	2·5	3·5	..
65	A. Zielke, Kepnock	2·3	1·1	0·9	0·2
66	A. Jacobsen, Gooburrum	3·3	0·4	0·7	..
67	W. G. Batchler, Gooburrum	3·3	0·4	1·1	..
68	E. A. Nielson, Gooburrum	4·1	0·4	1·1	..
69	B. H. Lehmann, Gooburrum	4·1	0·4	1·1	..
70	S. N. Gear, Gooburrum	2·5	0·4	0·4	..
71	B. J. Pegg, Oakwood	2·8	0·4	1·8	..
72	M. J. Hynes, Oakwood	1·9	1·1	0·9	0·2
73	Chase Bros., Gooburrum	2·8	0·2	0·7	..
74	Stitt and Sons, Sharon	3·9	1·8	0·4	1·4
75	Batchler and Rudder, Gooburrum ..	3·2	0·7	0·2	0·5
76	Warneminde and Cochrane, Gooburrum ..	4·6	0·2	2·6	..

farms on the tidal reaches of the rivers. Tests carried out on several such locations showed an increase in chlorine with continued pumping, strongly indicative of a connexion between the subterranean water-bearing bed and the tidal river. Boring on many similar properties also indicated small water beds of good quality at one depth and a much larger water bed of poor quality at a deeper level, the two beds being separated by a heavy clay stratum. Such a development at Millbank on the Burnett River, where the stream makes a sharp bend, suggests that part of the tidal water cuts across under this recent alluvial deposit and adulterates the subterranean water.

Cassidy (1944) has discussed ionic ratios of Queensland coastal waters and compared these ratios with those of sea water and the great rivers of the world. Similar ionic ratios for the Bundaberg district waters are shown in Table 6. The Na/Cl ratio is reasonably constant for both sub-basaltic and sub-forest waters, though there is an indication that it is slightly higher in

Table 3.

Sub-alluvial Waters.

No.	Farm Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Alkali.
		gr.p.g.	gr.p.g.	gr.p.g.	gr.p.g.
77	A. Scott, Millbank*	100·0	8·9	44·1	..
78	A. Scott, Millbank	36·0	16·2	6·7	9·5
79	A. W. Nielsen, Millbank	7·4	0·7	3·5	..
80	D. W. Clarry, Moorlands	88·0	5·1	19·3	..
81	W. H. Anderson, Moorlands	28·0	5·3	10·5	..
82	A. Toft, North Bundaberg	86·8	4·9	27·0	..
83	V. E. Tallon, North Bundaberg	52·4	3·5	39·9	..
84	J. Buchbach, Tegege*	138·0	23·6	28·0	..
85	J. Buchbach, Tegege*	47·5	10·7	13·7	..
86	S. E. Toft, Millbank	5·0	0·9	2·8	..
87	R. Geddes, Waterview	44·2	8·9	15·4	..
88	L. See Chin, North Bundaberg	28·6	0·5	19·6	..
89	J. Buchbach, Tegege	25·0	7·0	8·1	..
90	G. Broom, Avondale*	77·0	6·3	8·1	..
91	J. C. Twyford, Avoca	27·9	6·5	8·4	..
92	J. C. Twyford, Avoca (deep)*	176·5	6·2	36·9	..
93	W. Grimes, Tegege	9·8	3·0	4·9	..
94	K. P. Knudsen, Bonna	11·5	13·8	8·4	5·4
95	H. Wallace, New Bundaberg*	176·5	18·2	30·3	..
96	C. Rowland, Burnett Heads*	160·0	14·7	36·1	..
97	A. Hicks, Burnett Heads*	127·1	28·8	18·9	..
98	A. Ness, Rubyanna*	838·5	..	..	..
99	A. Ness, Rubyanna*	978·0	..	..	..
100	A. Ness, Rubyanna*	531·0	..	..	..
101	C. Rowland, Burnett Heads*	171·0	..	..	..
102	C. Rowland, Burnett Heads*	166·5	..	..	..
103	C. Rowland, Burnett Heads*	181·5	..	..	..

* Not being used for irrigation.

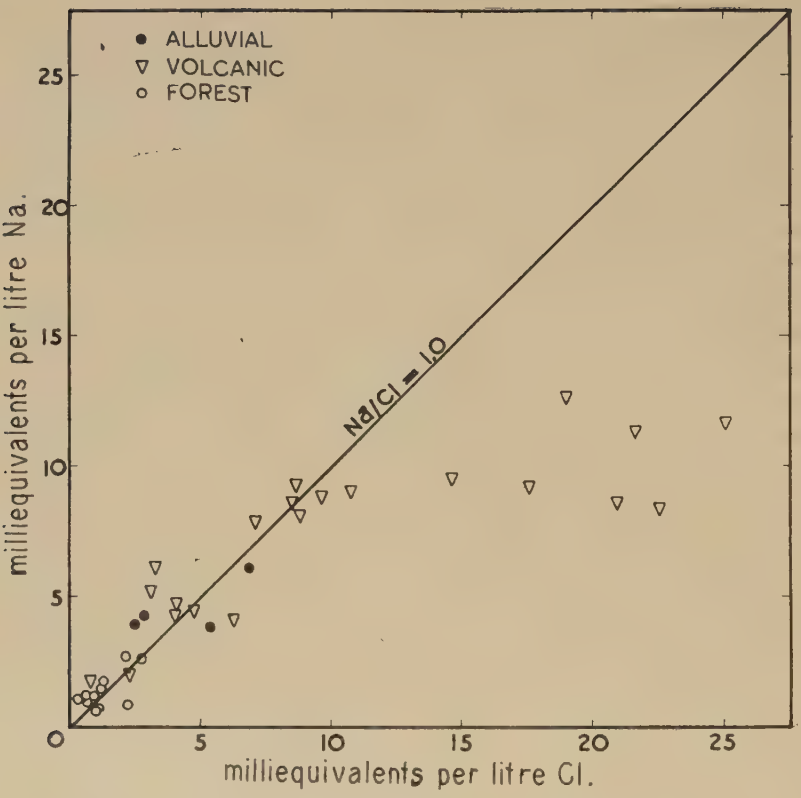

Figure 1.

Scatter diagram of Na/Cl ionic ratios for 36 waters.

the latter type. This is illustrated in Fig. 1, where the ionic concentrations of Na and Cl are plotted against each other. The Ca/Mg ratio is higher in the sub-forest waters, but the $\frac{Ca+Mg}{Na+K}$ and the HCO_3/Cl ratios are much higher in the sub-basaltic types. Some of these ratios diverge rather widely from those found by Cassidy for Queensland coastal waters; the divergence serves to indicate the variable quality of water supplies within that belt. All ratios, however, fall between those published for sea water on the one hand and the world rivers on the other and suggest the influence of cyclic salt.

In Table 4 are presented analyses of a cross section of the three type waters being used extensively in irrigation. The concentrations of the various ions are shown in milliequivalents per litre; in Table 5 they are expressed as a percentage of the total ion content. Major differences indicated by Table 4 are the much higher concentration of all ions in the sub-basalt type than in the sub-forest type and the intermediate position occupied by the sub-alluvial and river waters. The rather high Na concentration in the sub-basalt waters is not dangerous when the soil type and the ratio of divalent to monovalent ions are considered. The red basaltic loam is a very deep, well-drained, highly

Table 4.

ANALYSIS OF VARIOUS WATERS, SHOWING IONS IN MILLIEQUIVALENTS PER LITRE.

No.	Farm or Other Source.	Cl^-	HCO_3^-	$SO^=$	Ca^{++}	Mg^{++}	Na^+	K^+
	Basaltic Type Samples							
6	Qunaba Mill	26·32	4·13	3·57	4·29	10·58	12·42	·13
7	Qunaba Mill	19·15	3·21	3·08	5·54	8·66	12·65	·26
5	Qunaba Irrigation	7·20	2·79	1·54	1·36	3·20	7·85	·20
11	Jorgensen Bros., Burnett Heads	6·99	2·39	1·37	1·74	4·67	5·74	·18
12	Spring Hill Plantation.. ..	8·67	2·55	1·68	1·66	4·10	8·67	·19
8	R. G. Strathdee, Burnett Heads	10·80	3·26	2·64	5·90	2·08	8·98	·21
15	T. Young, Qunaba	4·73	2·30	1·27	1·06	3·30	4·55	·19
14	W. Slane, Qunaba	4·28	2·51	1·10	1·00	2·37	4·68	·20
16	R. M. Hurley, Sandhills Road	4·17	2·58	1·28	1·18	3·23	4·48	·17
10	F. Zielke, Ashfield Road ..	17·60	1·69	2·14	2·52	10·74	9·32	·20
18	G. C. C. Maughan, Gahan's Road	21·01	0·74	2·57	4·32	9·84	8·64	·18
3	Sugar Experiment Station ..	0·80	1·31	0·34	0·60	0·58	1·79	·18
17	H. Skyring, Wawoon	2·42	0·45	0·68	0·40	0·97	2·01	·07
20	J. C. Maughan, Seaview Road	56·32	3·18	3·05	2·60	9·34	53·63	·18
13	W. C. Stockwell, Springfield ..	5·46	0·44	0·27	0·62	1·87	3·88	·07
19	A. W. Bates, South Kolan ..	6·48	0·70	0·14	0·42	0·93	4·09	·06
31	G. Mangano, Barolin Road ..	22·75	2·17	2·46	2·70	10·03	8·41	·21
	Forest Type Samples							
50	W. Truscott, South Kalkie ..	0·60	0·08	0·20	0·05	0·36	1·27	·07
49	C. E. Tesch, South Kalkie ..	0·60	0·08	0·20	0·40	0·22	1·11	·07
58	Thiele Bros., Alloway	1·18	0·21	0·16	0·48	0·18	1·04	·08
60	B. Anderson, Alloway ..	1·07	0·20	0·03	0·18	0·43	0·91	·07
48	R. Lerch, South Kalkie ..	1·02	0·16	0·12	0·30	0·29	0·96	·06
104	M. W. Hiscock, Alloway ..	1·02	0·16	0·55	0·20	0·29	0·89	·08
55	F. J. Walk, South Kalkie ..	2·53	0·04	0·21	0·10	0·61	2·65	·07
52	F. Jacobsen, South Kalkie ..	2·31	0·04	0·20	0·25	0·31	1·96	·09
67	W. G. Batchler, Gooburrum ..	0·80	0·08	0·52	0·05	0·18	1·01	·07
70	S. Gear, Gooburrum	0·62	0·08	0·34	0·18	0·22	1·13	·05
107	Waimea Plantation	1·24	0·12	1·03	0·20	0·32	1·79	·06
62	G. Torrisi, Kepnock	1·20	0·08	0·24	0·16	0·32	1·34	·07
63	L. Kent, Kepnock	1·41	0·12	0·23	0·17	0·31	1·72	·06
105	Bundaberg North Water Supply	2·25	0·23	0·96	0·36	0·82	2·78	·06
	Alluvial Type Samples							
94	K. P. Knudsen, Bonna ..	2·80	3·23	1·06	1·26	1·58	4·23	·06
91	J. C. Twyford, Avoca	6·80	1·52	0·51	0·78	2·22	6·19	·05
106	Burnett River (above weir) ..	5·41	1·97	0·98	1·20	2·51	3·94	·02

flocculated soil containing upwards of 15 m.e. per cent. of total replaceable bases, of which Ca and Mg constitute over 90 per cent. It is also shown in Table 6 that, despite the high Na concentration in these waters, the Ca + Mg/Na + K ratio averages ·86 and that only two of the waters have a ratio below ·5.

Present day opinion on irrigation water quality tends to rely more on this ratio of divalent to monovalent ions than on the actual concentration of

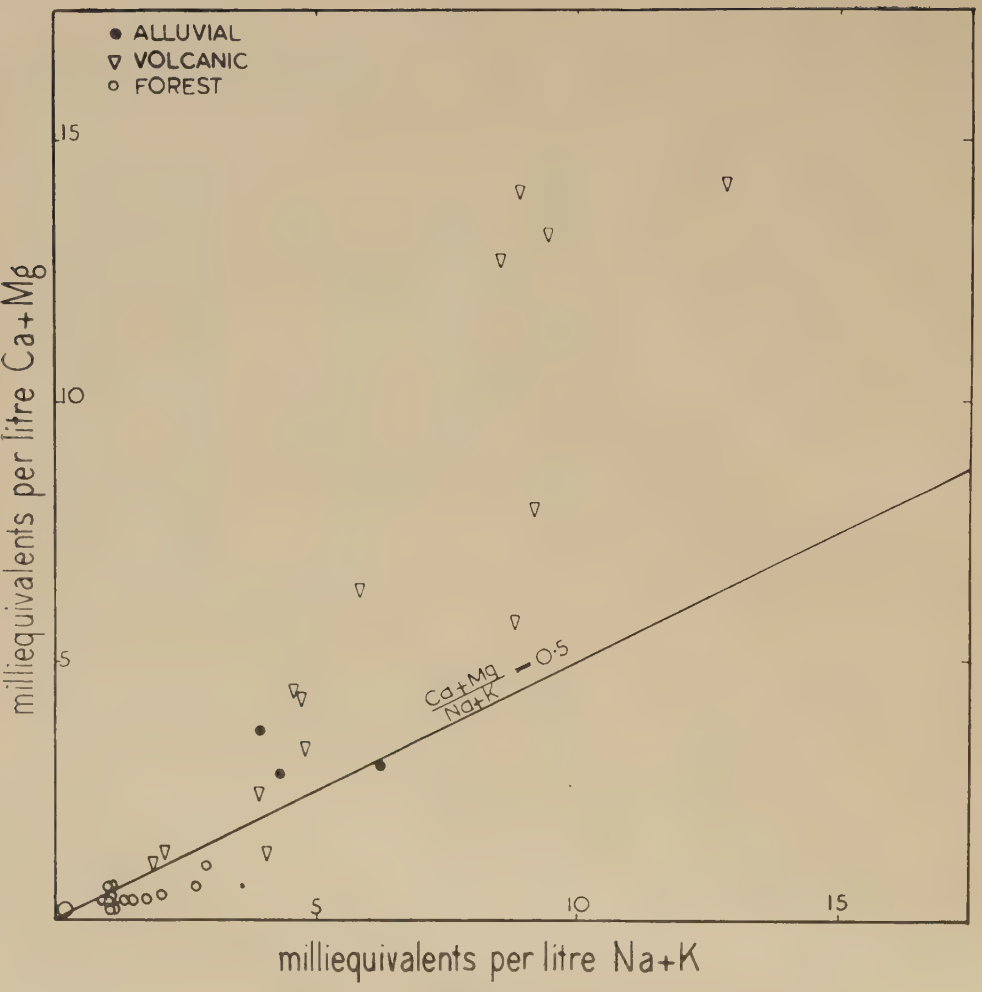

Figure 2.

Scatter diagram of Ca + Mg/Na + K ionic ratios for 30 waters.

the individual elements. Cassidy has discussed this ratio as a "Figure of Merit" of an irrigation water, since it gives a measure of the likely base exchange reaction with the soil. An undesirable physical condition of the soil is readily induced by the use of water with a low ratio of divalent to monovalent ions, but so long as the ratio remains above 0·5 the divalent bases appear to exert a beneficial influence in retaining good physical condition. Very broadly, the higher this ratio the better the water quality and, within ill-defined limits, the ratio is taken as the true quality index irrespective of the actual amounts of the ions present.

The "Figure of Merit" (f) for the sub-basalt waters in Table 6 is in the majority of cases well above 0·5 and exceeds unity in several. Of the two

waters where f is below 0·5, one has been used for 13 years without apparent change in the physical condition of the soil; the other has been in use for too short a period to gauge its effect.

Table 5.

ANALYSIS OF VARIOUS WATERS, SHOWING IONS AS PERCENTAGE OF TOTAL MILLIEQUIVALENTS.

No.	Farm or Other Source.	(Per cent of Total Milliequivalents.)						
		Cl^-	HCO_3^-	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	K^+
	Basaltic Type Samples							
6	Qunaba Mill	42·84	6·72	5·81	6·98	17·22	20·22	·21
7	Qunaba Mill	36·44	6·11	5·86	10·50	16·47	24·07	·49
5	Qunaba Irrigation	29·82	11·55	6·37	5·63	13·25	32·51	·82
11	Jorgensen Bros., Burnett Heads	30·28	10·39	5·93	7·53	20·23	24·87	·78
12	Spring Hill Plantation.. ..	31·50	9·26	6·08	6·03	14·89	31·50	·69
8	R. G. Strathdee, Burnett Heads	31·88	9·62	7·79	17·41	6·14	26·51	·62
15	T. Young, Qunaba	27·18	13·21	7·29	6·09	18·96	26·09	1·09
14	W. Slane, Qunaba	26·51	15·55	6·81	6·19	14·67	28·99	1·23
16	R. M. Hurley, Sandhills Road	24·40	15·09	7·48	6·90	18·89	26·21	·99
10	F. Zielke, Ashfield Road ..	39·81	3·82	4·84	5·70	24·29	21·08	·45
18	G. C. C. Maughan, Gahan's Road	44·41	1·56	5·43	9·13	20·80	18·26	·38
3	Experiment Station	14·28	23·39	6·07	10·71	10·35	31·96	3·03
17	H. Skyring, Wawoon	34·57	6·42	9·71	5·71	13·85	28·71	1·00
20	J. C. Maughan, Seaview Road..	43·89	2·47	2·37	2·02	7·27	41·80	·14
13	W. C. Stockwell, Springfield ..	43·29	3·48	2·14	4·91	14·82	30·76	·55
19	A. W. Bates, South Kolan ..	50·54	5·30	1·09	3·27	7·25	32·00	·46
31	G. Mangano, Barolin Road ..	46·68	4·45	5·04	5·54	20·58	17·25	·43
	Forest Type Samples							
50	W. Truscott, South Kalkie ..	22·81	3·04	7·60	1·90	13·68	48·28	2·66
49	C. E. Tesch, South Kalkie ..	22·38	2·98	7·46	14·92	8·20	41·41	2·61
58	Thiele Bros., Alloway	35·43	6·30	4·80	14·41	5·40	31·23	2·40
60	B. Anderson, Alloway ..	37·02	6·92	1·03	6·22	14·87	31·48	2·42
48	R.Lerch, South Kalkie ..	35·05	5·49	4·12	10·30	9·96	32·98	2·06
104	M. W. Hiscock, Alloway ..	31·97	5·01	17·24	6·26	9·09	27·89	2·50
55	F. J. Walk, South Kalkie ..	40·74	·64	3·38	1·61	9·82	42·67	1·12
52	F. Jacobsen, South Kalkie ..	44·76	·77	3·87	4·84	6·00	37·98	1·74
67	W. G. Batchler, Gooburrum ..	29·52	2·95	19·18	1·84	6·64	37·26	2·58
70	S. Gear, Gooburrum	23·66	3·05	12·97	6·87	8·39	43·12	1·90
107	Waimea Plantation	26·05	2·52	21·64	4·20	6·72	37·61	1·26
62	G. Torrisi, Kepnock	35·18	2·05	7·03	4·69	9·38	39·29	2·05
63	L. Kent, Kepnock	35·07	2·98	5·72	4·22	7·71	42·78	1·49
105	Bundaberg North Water Supply	30·16	3·08	12·86	4·82	10·99	37·26	·80
	Alluvial Type Samples							
94	K. P. Knudsen, Bonna ..	19·65	22·71	7·45	8·86	11·11	29·80	·42
91	J. C. Twyford, Avoca	37·63	8·41	2·82	4·31	12·23	34·25	·27
106	Burnett River (above weir) ..	33·74	12·28	6·11	7·48	15·65	24·57	·12

The f value of the sub-forest waters is not so favourable, averaging only 0·39 for the 13 samples fully analysed. However, since the total of the four ions averages only 2 milliequivalents per litre, the possibility of any appreciable deterioration in soil structure due to watering is slight. Further, the soils are well drained and the periodic lime applications which are made to counteract soil acidity also guard against the development of too high a proportion of Na in the base exchange complex. Observant farmers state that they are

Table 6.

Ionic Ratios of Bundaberg and Other Waters.

No.	Farm or Other Source.	Na/Cl	Ca/Mg	$\frac{Ca+Mg}{Na+K}$	HCO_3/Cl
6	Qunaba Mill	0·47	0·41	1·18	0·16
7	Qunaba Mill	0·66	0·64	1·10	0·17
5	Qunaba Irrigation	1·09	0·42	0·57	0·39
11	Jorgensen Bros.	0·82	0·37	1·08	0·34
12	Spring Hill Plantation	1·00	0·40	0·65	0·29
8	R. G. Strathdee	0·83	2·80	0·87	0·30
15	T. Young	0·96	0·32	0·92	0·49
14	W. Slane	1·09	0·42	0·70	0·59
16	R. M. Hurley	1·08	0·37	0·95	0·62
10	F. Zielke	0·53	0·23	1·39	0·09
18	G. C. C. Maughan	0·41	0·44	1·61	0·04
3	Sugar Experiment Station	2·35	1·04	0·59	1·64
17	H. S. Skyring	0·83	0·41	0·66	0·19
31	G. Mangano	0·82	0·26	1·48	0·10
13	W. C. Stockwell	0·71	0·33	0·63	0·08
19	A. W. Bates	0·63	0·45	0·32	0·11
20	J. C. Maughan	0·95	0·28	0·22	0·05
50	W. Truscott	2·11	0·14	0·30	0·14
49	C. E. Tesch	1·80	1·90	0·52	0·14
48	R. Lerch	0·94	1·00	0·57	0·16
104	M. W. Hiscock	0·87	0·69	0·50	0·16
60	B. Anderson	0·85	0·42	0·62	0·19
58	Thiele Bros.	0·88	2·70	0·59	0·18
55	F. J. Walk	1·05	0·16	0·26	0·02
52	F. Jacobsen	0·85	0·83	0·27	0·02
67	W. G. Batchler	1·27	0·28	0·21	0·10
70	S. N. Gear	1·83	0·84	0·33	0·13
107	Waimea Plantation	1·44	0·63	0·28	0·10
62	G. Torrisi	1·12	0·49	0·34	0·07
63	L. Kent	1·22	0·56	0·27	0·09
94	K. P. Knudsen	1·51	0·80	0·66	1·15
91	J. C. Twyford	0·91	0·35	0·48	0·22
106	Burnett River (above weir)	0·73	0·40	0·90	0·36
105	Bundaberg North Water Supply	1·24	0·44	0·42	0·10
	River Waters (World)	1·6	3·7	4·3	7·3
	Sea Water	0·85	0·2	0·27	0·005
	Average of some inland rivers	0·83	0·91	1·75	1·00
	Hawaiian Irrigation waters (average)	0·9	0·8	1·1	0·9

Table 7.

UNSUITABLE WATERS AWAY FROM TIDAL INFLUENCE.

No.	Farm or Other Source.	Chlorides as NaCl.	Total Alkalinity.	Total Hardness.	Free Acidity.
		gr. p.g.	gr. p.g.	gr. p.g.	
108	W. H. Grieving, Rosedale	440	18·7	76·3	..
109	W. E. A. Cross, Rosedale	390	13·1	75·6	..
110	W. J. Lucke, Kolan Road South	692	nil	71·0	3·85
111	W. J. Lucke, Kolan Road South	1,550	nil	89·6	1·58
112	E. Grills, Watalgan	541	39·7	60·6	..
113	C. W. Hood, Kolan Road South	869	nil	69·0	12·3
114	C. W. Hood, Kolan Road South	1,286	..	..	..
115	G. B. Pignat, Mullet Creek	991	nil	72·1	2·8
116	F. Hales, Rosedale	229	25·4	82·3	..
117	G. W. Moore, Kolan Road South	446	..	..	..
118	Snake Creek (Waterhole)	1,031	6·1	80·0	..
119	Bauer Bros., Watalgan	188	nil	37·5	2·1

noting a deterioration of the tilth of their forest soils after 10 or 12 years of irrigation, but this, if true, is more likely to be caused by a breakdown in crumb structure due to the alternate wetting and drying and the puddling of the wet soil by irrigators than by an increase in sodium in the clay fraction. The amounts of exchangeable sodium in irrigated and non-irrigated soils do not indicate any significant increase after years of watering.

In order to illustrate the inadvisability of judging an irrigation water on its total ionic content, the following brief account of tests carried out with No. 6 water on a red basaltic soil is given. The composition of the water, as given in Tables 1 (a) and 4 shows both chlorides and total solids to be very high. Five months after irrigation with this water a sample of soil was taken and analysed, and a sample from an adjacent non-irrigated field was also collected and analysed. Part of the sample of the irrigated soil was placed in a cylinder, given an artificial 20-inch irrigation with the water concerned, and analysed. A further sample from the irrigated field was taken after a fall of five inches of rain and analysed. The four analyses are given below.

Soil.	Replaceable Bases m.e. per 100 gms.			
	Ca.	Mg.	Na.	K.
No. 1 Irrigated for five months	32·9	13·1	1·05	0·43
No 2 Same as No. 1 but extra 20 ″ irrigation	33·3	12·5	1·2	0·35
No. 3 Same as No. 1 after 5″ rain	20·8	10·5	1·2	0·35
No. 4 Non-irrigated soil	13·8	5·9	0·59	0·16

Ca and Mg showed marked increases after five months irrigation, but the extra 20-inch irrigation did not alter the figures significantly. The leaching with 5 inches of rain, however, caused a considerable reduction in Ca and to a less marked extent in Mg. Na doubled with 5 months under irrigation and

Table 8.

IRRIGATION PLANT DATA IN THE BUNDABERG AREA*.

Name.	Address.	Depth to Drift.	Number and Size Spears.	Size and Type of Pump.	Depth to Static Water Level.	Draw-Down.	Engine H.P.	Pumping Capacity per Hour.
		Feet.		Inches.	Feet.	Feet.		Galls.
Sub-basaltic Irrigation Plants.								
A. W. Bates and Sons	South Kolan	71	No spears	7 ver.	25	5	40	40,000
J. Chappell	Burnett Heads	60	ditto	$\frac{5}{6}$ hor.	37	16	24	30,000
G. Fabricato	Pemberton	26	2 x 4 in.	4 ver.	40	2	10	16,000
Fairymead Sugar Co.	Springhill	..	3 x 6 in. + open 12 in. pipe	12 hor.	55	10	125	100,000
R. M. Hurley	Sandhills Road	72	nil	4 hor.	36	18	28	16,000
Jorgensen Bros.	Burnett Heads	95	nil	6 ver.	70	20	50	40,000
J. Lutz	Sandhills Road	91	nil	$\frac{3}{4}$ hor.	35	23	..	16,000
G. C. C. Maughan	Gahan's Road	36	2 x 4 in. 1 x 2½ in.	4 hor.	36	5	18	20,000
J. C. Maughan	"Fairfield"	40	nil	3 hor.	33	4	..	12,000
W. Shaw	Burnett Heads	88	1 x 5 in. 1 x 6 in.	6 hor.	70	16	47	30,000
W. C. Stockwell (1)	Springfield	45	2 x 4 in.	4 hor.	27	6	14	13,000
W. C. Stockwell (2)	Springfield	..	3 x 3 in. 1 x 2 in.	4 hor.	30	6	8	15,000
R. G. Strathdee	Burnett Heads	33	1 x 5 in.	4 her.	34	..	13	15,000
T. Young	Rubyanna	107	nil	6 ver.	66	12	44	40,000
F. Zielke	Ashfield Road	79	2 x 4 in.	$\frac{3}{4}$ hor.	64	..	17	18,000
Sub forest-land irrigation plants.								
B. Anderson	Alloway	56	5 x 3 in. to 5 in.	5 hor.	60	3	28	20,000
W. G. Batchler	Gooburrum	55	5 x 5 in.	7 hor.	30	7	34	55,000
Batchler and Rudder	Gooburrum	53	3 x 5 in.	6 hor.	27	5	31	45,000

Chase Bros.	Gooburrum	42	2 x 4 in. 1 x 2½ in.	4 hor.	50	1	18	16,000
W. Douglas	Coonarr Road	68	2 x 6 in. 2 x 4 in.	6 ver.	45	4	30	40,000
Fairymead Sugar Co.	Waimea	..	14 x 6 in.	12 hor.	16	..	125	100,000
A. Jacobsen	Maryborough Road	62	2 x 4 in.	⅘ hor.	63	2	30	20,000
A. Jacobsen	Gooburrum	75	3 x 4 in. 1 x 3 in.	5 hor.	36	3	19	20,000
F. Jacobsen	South Kalkie	30	3 x 6 in.	7 hor.	28	4	34	65,000
H. Lerch	South Kalkie	55	2 x 4 in.	5 hor.	40	5	15	25,000
R. Lerch	South Kalkie	39	1 x 4 in.	4 ver.	30	7	10	17,000
W. T. Hopkins	South Kalkie	34	2 x 6 in. 1 x 5 in.	7 ver.	34	2	27	55,000
G. Marano	South Kalkie	58	4 x 4 in.	6 ver.	30	10	37	45,000
S. Marano	South Kalkie	42	3 x 3 in.	5 ver.	43	..	22	30,000
V. Parisi	South Kalkie	35	1 x 4 in.	4 hor.	38	3	8	14,000
P. Plath	South Kalkie	25	2 x 4 in.	5 hor.	38	1	15	25,000
Stitt and Sons	Sharon	60	2 x 6 in.	4 hor.	43	..	15	17,000
C. E. Tesch	South Kalkie	61	2 x 5 in. 1 x 3 in.	6 hor.	53	2	25	28,000
Thiele Bros.	Alloway	60	2 x 6 in.	7 ver.	60	4	42	50,000
J. T. Thiele	South Kalkie	35	1 x 4 in. 2 x 3 in.	4 hor.	37	2	16	20,000
G. Torrisi	Kepnock	70	2 x 4 in.	5 hor.	50	2	25	30,000
W. Truscott (1)	South Kalkie	40	1 x 4 in. 1 x 3 in.	4 hor.	40	1	12	20,000
W. Truscott (2)	South Kalkie	42	1 x 5 in. 1 x 3 in.	5 hor.	42	2	13	27,000
F. J. Walk	South Kalkie	36	2 x 5 in.	5 ver.	36	2	17	30,000
A. Zielke	Kepnock	55	2 x 4 in.	⅜ hor.	45	..	30	30,000

*NOTE.—This is not a complete list of Bundaberg irrigation plants, but is a cross section taken to illustrate the local conditions.

became still higher with the 20-inch artificial watering. This figure was not reduced by rain. The effect of the potash content of the water in increasing the exchangeable potassium in the soil is noticeable.

These results indicate that the water, far from being of poor quality, as its total solids and total chloride content would suggest, is of good quality for irrigation purposes. This fact is reflected by the Figure of Merit for the water, which is 1·11.

The miscellaneous waters of which the partial analyses are shown in Table 7 are all from areas which are not influenced by tidal streams. Depths of the wells or bores vary from 10 feet to 100 feet, and they were put down during the 1945-46 drought in search of water supplies either for irrigation or for stock. These, and many others analysed in recent years. indicate the presence of highly saline springs over a wide area of this district. The sample from Snake Creek was taken when the stream had ceased running, and it was noticed that horses would not drink the water in the series of waterholes. Adulteration by a saline spring is apparent from the analysis. At least two of the four waters containing free acid are from shallow wells in tea-tree swamp areas where considerable depths of organic residues were in existence.

The area in which all of these unsuitable waters were located is a development of marine tuffaceous beds of Cretaceous age which runs in an arcuate band through Childers, Booyal, and Bullyard to Baffle Creek This geological formation appears to be associated with saline springs, in some of which the salt content is abnormally high.

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THE MANUFACTURE OF A NON-FAT-LEAKING CHEDDAR CHEESE FROM RECONSTITUTED MILK.

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SUMMARY.

A process has been evolved for the commercial manufacture of a non-fat-leaking cheddar cheese.

The process depends on separating the whole milk, homogenizing the cream therefrom in a three-stage homogenizer to reduce most of the fat globules to less than 2μ in diameter, reconstituting the milk, and proceeding as in cheddar cheese manufacture, with minor modifications.

The underlying principles of homogenization, the method of manufacture, defects and their control, equipment and its layout, and costs of manufacture are discussed.

INTRODUCTION.

There has long been a need for a cheese which would be as attractive to eat in the tropics and hot inland regions of Queensland as ordinary cheddar in temperate climates. Cheddar cheese "sweats" freely when atmospheric temperatures are high, and its edible life is very short where refrigeration is not available.

In view of the increased importance of cheese as a wartime foodstuff in Great Britain and its possible production as an alternative to butter at a time when refrigerated vessels were difficult to secure for the Australian trade, investigations were initiated, in conjunction with the Queensland Butter Board, to produce a cheese which would not leak fat when subjected to high temperatures, and which would stand up to long periods of holding as unrefrigerated cargo. Apart from the advantages of a non-fat-leaking cheese in transport, its more extensive use in the tropics and hot inland regions could not be overlooked.

PRINCIPLE OF THE METHOD.

A cheddar cheese which is strongly resistant to fat leakage may be manufactured by separating the whole milk, homogenizing the cream so as to reduce the size of most of the fat globules from approximately 10μ to less than 2 μ in diameter, and then reconstituting the milk. For a satisfactory product it was found that 85 per cent. of the fat globules should be less than 2μ in diameter, well dispersed, and exhibit Brownian movement when viewed microscopically. When fat-globular clumping was evident, the homogenized

cream became too viscous and the cheese made from the reconstituted milk exuded fat at high atmospheric temperatures. To prevent the clustering of the fat globules, it was found necessary to use an emulsifying agent, irrespective of the number of phases of homogenization.

The first-phase homogenization at high pressure results in a splitting of the fat globules and a subsequent clustering. Assisted by an emulsifying agent, the second and third phases at low pressures cause a complete dispersal of the globules. Plates 1–5 illustrate these changes.

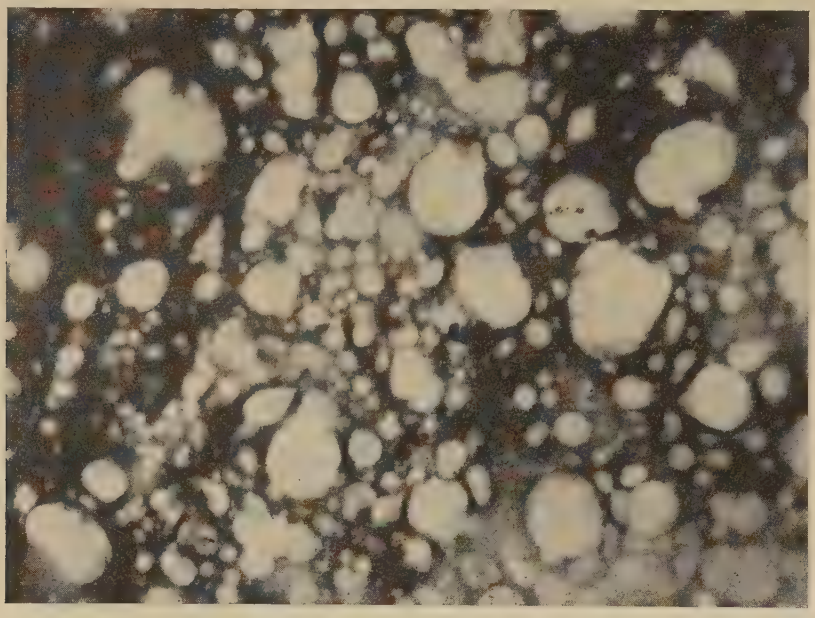


Plate 1.

Photomicrograph of fat globules in normal milk. (Diameter approx. 10 microns) × 1000.

If the homogenization is efficient, the fat globules are so finely dispersed that, after reconstitution with skim milk, each globule is completely and permanently encased by the milk serum. As the non-fat-leaking characteristic of the cheese depends essentially upon size and dispersion of the fat globules, the smaller the fat globules and the more even the dispersion, the more effectively are they incorporated in the reconstituted milk and the greater the resistance to fat leakage of the resulting cheese.

The method first attempted was to homogenize whole milk, but destabilization of the casein gave a "soft curd." It was ultimately found that homogenization of the cream portion, and not of the whole milk, was the key to the procedure.

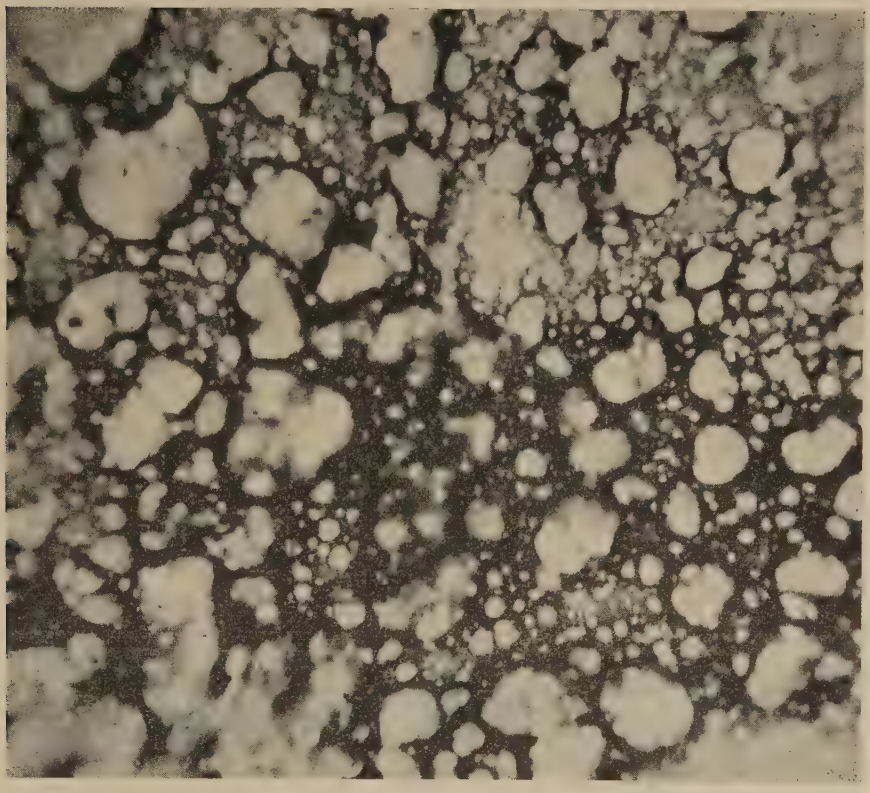


Plate 2.
Fat globules in normal cream × 1000.

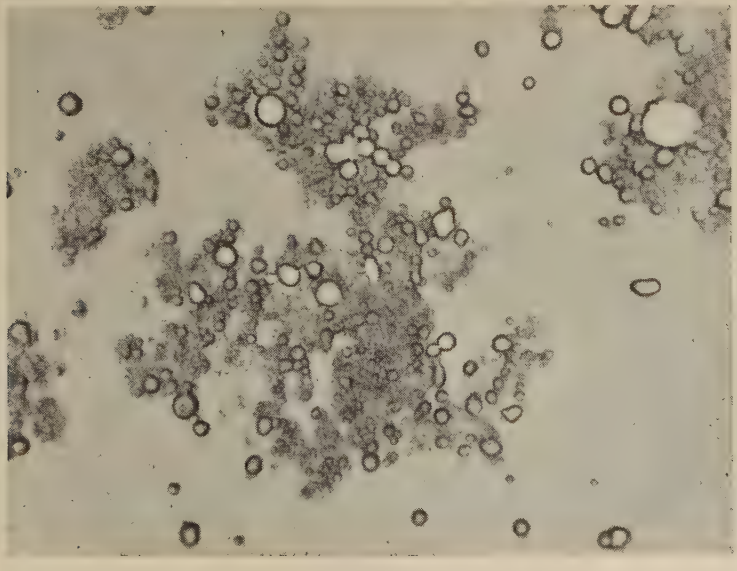


Plate 3.
Illustrating typical clumping of fat globules after first stage homogenization × 600.

EFFICIENCY OF HOMOGENIZATION.

The effects of the following factors on the efficiency of homogenization were studied by microscopic examination and observation of the cheese when held at high atmospheric temperatures:—

(1) Number of stages of homogenization and homogenizing pressures.

(2) Temperature of homogenization.

(3) Quantity and kind of emulsifier.

(4) Fat content of the cream.

(5) Acidity of the cream.

(6) Use of calcium salts in casein deficient milk.

(7) Excessive agitation or frothing in treating and reconstituting the milk.

Number of Stages of Homogenization and Homogenizing Pressures.

Single-stage homogenization at 1,500 lb. per square inch pressure gave excessive fat clumping with thickening of the cream (see Plate 3). The two-

Plate 4.

Fat globules in cream of 20 per cent. fat content following 3-stage homogenization.

stage process at 1,250 lb. and 500 lb. pressure respectively resulted in a partial clumping of the fat globules, though the cream was less viscous than with single-stage homogenization at 1,500 lb. In these trials numerous fat globules exceeded 2μ in diameter, with some fat leakage in the resultant cheese. With first-stage pressure at 2,500 lb. to 3,000 lb., followed by 500 lb. pressure in the second stage, there was some clumping of the fat globules, with some fat leakage from the cheese.

The three-stage process, at 2,200 lb., 650 lb. and 150 lb. pressure in the first, second, and third stages respectively, gave satisfactory results; 85 per cent. of the fat globules were less than 2μ in diameter and well dispersed, and the cream was of the desired consistency.

Temperature of Homogenization.

Temperatures of 125°F., 145°F., 160°F., 170°F. and 180°F. were tried. At the higher temperatures of 160°F. and above, homogenization was most efficient, and fat clumping reduced. A temperature of 160°F. was finally decided upon to prevent a cooked flavour, as well as to ensure the complete destruction of lipolytic enzymes.

Quantity and Kind of Emulsifier.

Irrespective of the number of stages of homogenization, it was found necessary to use an emulsifier to aid the dispersal of the fat globules in the second and third stages.

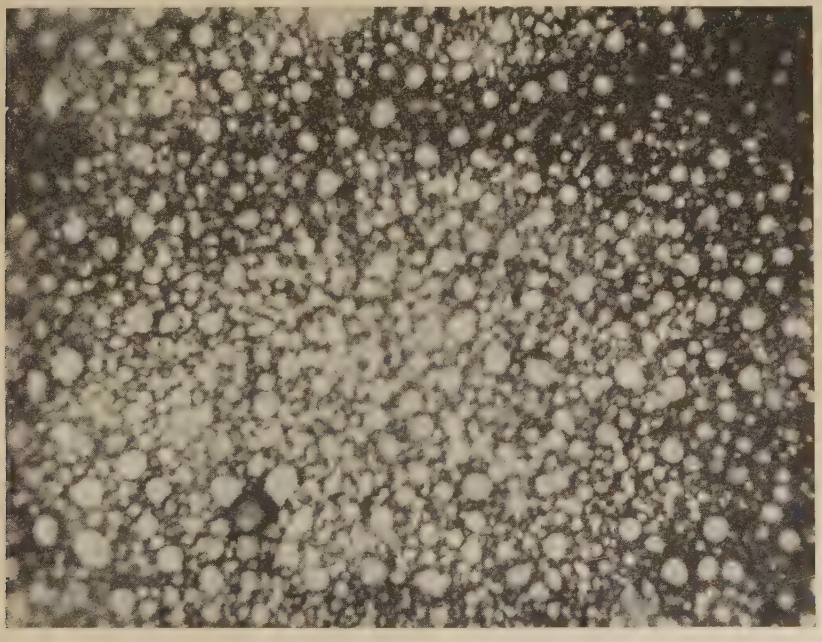


Plate 5.

Photomicrograph of fat globules in the reconstituted milk. (Diameter approx. 2 microns.)

Di-sodium hydrogen phosphate (0·1 per cent., 0·2 per cent., 0·25 per cent., 0·5 per cent., 0·75 per cent., 1 per cent. and 1·25 per cent.) and sodium citrate (0·1 per cent., 0·2 per cent., 0·3 per cent., 0·4 per cent., 0·5 per cent., 0·75 per cent. and up to 1 per cent.) were used in trial batches. Since sodium citrate gave more satisfactory results than di-sodium hydrogen phosphate, it was finally chosen as the emulsifying agent. Use of di-sodium hydrogen phosphate up to 1·25 per cent. resulted in fat clumping, thickening of the cream and fat leakage in the cheese. Use of sodium citrate below 0·75 per cent. gave different degrees of fat clumping, depending upon the quantity used. Sodium citrate was noted to impart a slight bitterness to cheese if used in excess of 0·75 per cent., and its use was limited to this quantity. As a further aid to reducing the citrate flavour, the cream was diluted with an equal quantity of hot water at 160°F.

Fat Content of the Cream.

When whole milk was homogenized there was efficient splitting and dispersal of the fat globules. As already mentioned, however, the casein was completely destabilized and the milk rendered unsuitable for the manufacture of cheddar cheese.

When a 38 to 40 per cent. fat content cream was homogenized, a large percentage of the fat globules exceeded 2μ in diameter, and a tendency to fat clumping was evident.

Homogenization of cream separated to 20 per cent. fat content resulted in casein destabilization due to the high serum-solids content, and there was a characteristic curd flaking in the whey. Efficient separation of a 20 per cent. fat content cream was found difficult.

The addition of an equal volume of skim milk to 40 per cent. fat content cream to reduce the fat content to 20 per cent. also resulted in casein destabilization, though in each case homogenization was efficient.

The replacement of the skim milk by an equal quantity of hot water to reduce the fat content of the mixture to 20 per cent. for homogenization gave satisfactory results.

Acidity of the Cream.

During the summer months the higher acidities in milk and cream (over 0·2 per cent.) caused excessive fat clumping and increased fat leakage from the cheese. Developed acidity in treated cream also caused excessive fat clumping and thickening. To obviate these disadvantages, small amounts of sodium bicarbonate were added to reduce the acidity of the milk to 0·18 per cent. calculated as lactic acid.

Effect of a High Calcium Content in the Milk.

Calcium chloride is sometimes added to milk with a view to improving the body and texture of cheese. Its use in reconstituted milk was discontinued after the initial trials, as it encouraged clumping of the fat globules.

Excessive Agitation or Frothing in Reconstitution.

Excessive agitation or frothing during treatment of the milk caused clumping of the fat globules in the reconstituted milk and a rough-textured curd. Consequently, efforts were made to reduce agitation and frothing during treatment and reconstitution. Fine wire gauze strainers were used over the reconstituting vat to minimise frothing of the skim milk. Where possible the skim milk, the homogenized cream, and the reconstituted milk were allowed to gravitate rather than be subjected to pumping. Where pumping could not be avoided, centrifugal pumps were installed. Immediate reconstitution of the skim milk and homogenized cream at the separated milk outlet of the separator, at the same temperature, also reduced frothing.

Testing Efficiency of Homogenization with the Microscope.

Microscopic observations on the homogenized milk and the behaviour of the cheese at high temperatures were used as criteria of efficiency of homogenization. Microscopically, when approximately 85 per cent. of the fat globules were broken up to 2μ or less in diameter without clumping, the resultant cheese showed no fat leakage. Counting the size and frequency of the fat globules in an effort to determine an homogenizing index (Farrel *et al*, 1942) also gave satisfactory results. However, the most important method was to observe the effect on the product.

Diluted suspensions in a hanging drop slide made from one part of homogenized cream to 99 parts of distilled water were examined with the oil immersion objective of the microscope. Reconstituted milk was similarly examined by using 10 parts to 90 parts of distilled water. Distilled water was used, because electrolytes in the water may effect clumping of the fat globules. A small drop of the dilution was placed on a cover glass and inverted over the depression in the hanging drop slide. The prepared slide was then examined with the oil immersion lens and the size of the globules and the degree of dispersion could be readily determined. The size of the globules may be measured with the aid of a filar micrometer calibrated against a stage micrometer. In many instances, however, mere observation determined whether the fat globules had been properly broken up, and curd tests confirmed the resistance to fat leakage.

A NOTE ON BABCOCK BUTTERFAT TESTS OF HOMOGENIZED CREAM AND RECONSTITUTED MILK.

The very fine state of division of the fat globules in the reconstituted milk necessitated certain modifications of the Babcock test to obtain accurate butterfat tests.

The normal butyl alcohol modification of the Babcock test (4 ml. of alcohol and 17·6 ml. of reconstituted milk) gave butterfat tests which were in agreement with those from the original milk. The same modification also gave slightly higher results than the Babcock test of the whey and homogenized

cream. The data in Table 1 show that the modified Babcock test gave results on cheese which compared favourably with those secured by the the Roese-Gottleib method (Association of Official Agricultural Chemists, 1945). No difficulty was experienced in obtaining clear char-free fat columns (Trout and Lucas, 1945).

Table 1.

TYPICAL RESULTS OF BUTTER-FAT TESTS BY ORDINARY BABCOCK AND NORMAL BUTYL ALCOHOL METHODS.

	Milk or Cream.	Milk or Cream after Homogenization.	
	Babcock Test.	Babcock Test.	Normal Butyl Alcohol Modification.
	%	%	%
Milk	3·6	3·3	3·6
Milk	3·6	3·4	3·7
Cream 9 gr.	25·0	21·0	26·0
Cream 9 gr.	38·0	33·0	39·0
	Roese-Gottleib Method.	Normal Babcock Method.	Butyl Alcohol Modification.
	%	%	%
Whey	..	0·08	0·09
Whey	..	0·07	0·08
Fat in cheese	33·4	31·8	33·2
Fat in cheese	35·0	33·4	34·5

EVOLVING A COMMERCIAL PROCESS.

Following the development of an efficient system of homogenization, and the manufacture of experimental batches of non-fat-leaking cheddar cheese, efforts were made to evolve a system of manufacture on a commercial basis.

Initial Trials.

To reduce any financial loss while a suitable method of manufacture was being evolved, initial experiments were carried out with second-grade cream. These trials involved:—

(1) Separating the whole milk as received at the cheese factory.

(2) Pasteurizing the skim milk.

(3) Adding emulsifier to the cream and homogenizing at 145°F.

(4) Holding the cream for thirty minutes prior to cooling to 86°F.

(5) Mixing the skim milk and homogenized cream in the cheese vat.

(6) Following orthodox cheddar cheese manufacture.

This method was found impracticable, as it caused undue delays in factory routine.

It was considered that the process might prove more practicable if the cream were held overnight, then reconstituted and manufactured the following day. However, the holding of homogenized cream overnight presented difficulties: it necessitated additional refrigeration loads and vat storage space, and there was a loss of homogeneity. Normal cheddar cheese manufacture also proved unsuitable for this type of product.

In further trials the whole milk was separated, the cream homogenized and the milk reconstituted prior to pasteurization. However, this necessitated additional holding vats and delayed treatment. The abnormal physical characteristics of the reconstituted milk due to excessive frothing and agitation also affected cheese quality. A modified treatment in which the whole milk was pasteurized, then separated, homogenized and reconstituted, improved the physical characteristics of the milk. To increase the efficiency of separation, and for convenience of treatment, the temperature of the milk was raised from 98°F. to 160°F. Then followed the holding of the cream in hot-water jacketed vats to ensure destruction of lipase, emulsifying, homogenizing, and cooling to 88°F. prior to mixing in the cheese vat.

The quality of the cream did not appear to be affected by holding for 30 minutes at 160°F. either before or after homogenization. However, the quality of the manufactured product did not compare favourably with that of normal cheddar.

The process was further modified by reconstituting the skim milk and homogenized cream at the same temperature in a mixing vat just prior to being passed over the milk cooler, and gravitating it in the cheese-making vat. However, control of the texture and the condition of the manufactured product still presented difficulties.

The Continuous Process.

A continuous process was eventually evolved. The whole milk was pasteurized at 160°F. and this temperature was maintained throughout separation and homogenization. Immediately afterwards the milk was reconstituted at 160°F. in the reconstituting vat at the separated milk outlet of the separator. Each of the processes synchronised for continuous operation.

By maintaining a temperature of 160°F. for pasteurization, separation, homogenization, and reconstitution, lipolytic enzymes were destroyed and the bacteriological quality of the milk was improved. Physical agitation and frothing of the reconstituted milk was minimized and curd of normal texture resulted. If necessary during the summer months the milk was neutralized to 0·18 per cent. acidity for more effective separation and homogenization.

The following are the details of the continuous process:—

Separation.

The heated milk was taken direct from the pasteurizer to a high-power centrifugal (preferably foamless type) separator of 1,500 gallons-an-hour

capacity, where it was separated to approximately 40 per cent. fat content cream. The high temperature separation gave efficient skimming, the fat content of the separated milk averaging 0·02 per cent. by the normal butyl alcohol modification of the Babcock test. Though fat tests up to 0·08 per cent. on the separated milk did not affect the resistance of the cheese to fat leakage, separation should be efficient.

Separation removed much dirt and cellular material from the milk and benefited milk quality. To reduce frothing the separated milk was gravitated into the reconstituting vat through a fine-gauze stainless steel strainer.

To reduce the viscosity of the cream by dispersal of the fat globules in the second and third phases of homogenization, 0·75 per cent. sodium citrate as an emulsifier was added by means of a drip system at the cream outlet of the separator. One part of emulsifier was dissolved in three parts of water. The emulsified cream was then "boosted" in temperature by passage through a tubular heater to ensure 160°F. during homogenization, and afterwards gravitated to a stainless steel holding vat adjacent to the homogenizer.

Homogenization.

The cream was standardized to a fat content of 20 per cent. by adding an equal volume of water at 160°F. in the holding vat. The standardized, emulsified cream was then homogenized in a 270-gallon-an-hour capacity, three-stage homogenizer at pressures of 2,200, 650, and 150 lb. per square inch in the first, second, and third stages, respectively. The pressures were accurately checked both on the pressure gauge and electrically by means of an ammeter. By-passes ensured that all cream was subjected to uniform pressures and a continuous flow of homogenized cream to the reconstituting vat.

Reconstitution.

The separated milk and homogenized cream were reconstituted at the same temperature in the stainless steel reconstituting vat near the separated milk spout of the separator. Following reconstitution the milk was pumped over the cooler, cooled to setting temperature, and gravitated to the cheese-making vat. Biologically, the treatment improved the milk for cheese manufacture.

Observations on Manufacture.

Because of the altered physical characteristics of the reconstituted milk, the normal cheddar process was gradually modified as follows:—

(1) Lower acidities were needed at various stages because of the higher moisture retained by the curd and the longer "cooking" time.

(2) The comparatively soft curd necessitated a slightly higher setting temperature, the milk being set at 88°F.

(3) Twice the normal quantity of rennet was required to set the milk because of the added sodium citrate and neutralizer (if used).

(4) The curd was cut finer because of the tendency to retain moisture and, being soft, was handled gently.

(5) After cutting, the curd was stirred gently by hand for approximately 10 minutes, followed by "slow gear" mechanical agitation for a further 10 minutes, and finally "top gear' agitation. This prevented a cloudy whey and a flaky, crumbly curd.

(6) The control of the moisture content of the curd was difficult, and cooking temperatures from 2° to 4° above normal were necessary. Consequently, a thermoduric starter culture (*Streptococcus thermophilus*) was used in association with a *Streptococcus cremoris* culture in the proportions of approximately 0·16 per cent. of the former and 1·5 per cent. of the latter. The starters were propagated in separated milk to prevent fat leakage from the cheese.

A comparatively slow "cook" to a high temperature was necessary for effective moisture control. The temperature was raised to 104–106°F., as the casein/fat ratio demanded, in approximately 40 to 50 minutes; the lower acidity during manufacture permitted of the longer cooking time.

The whey was drawn when the acidity was 0·16 per cent.

(7) Special attention was given to cheddaring the curd in order to control moisture content and texture. At the commencement of cheddaring the acidity of the whey (0·22–0·24 per cent.) was lower than for normal cheddar cheese practice. Otherwise normal cheddaring was carried out. A short, rough crumbly texture resulted from defective cheddaring, and the finished product was dry and crumbly.

(8) After "wheying off" there was limited extrusion of whey or white whey.

In the later stages of manufacture every encouragement was given for acidity to develop, so that a normal textured curd, with the desired moisture content, could be produced. Vats were covered and temperatures were maintained at approximately 90°F. by injecting steam into the jackets of the vats.

Despite a characteristic short and rough texture, the curd pressed well, giving a close-textured product.

(9) With a view to further improving the texture of the cheese, a system of manufacture reported to be successful in America (Wilson, 1945) was tried. The main departure from the procedure adopted is in the lower acidities developed at various stages of manufacture. The method compared favourably with the manufacturing procedure outlined, effecting a similar improvement in the texture of the cheese.

COMPOSITION OF THE CHEESE.

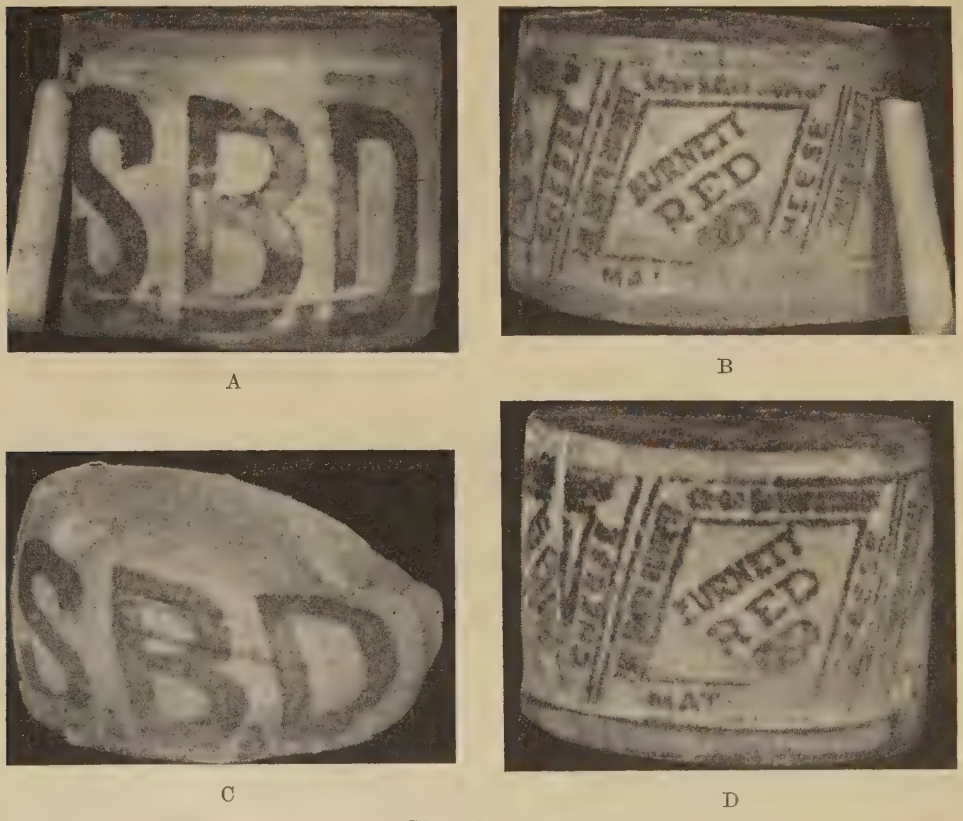
A typical analysis of the cheese (21 days old) is:—

Moisture	37·3%
Fat	33·5%
Salt	1·8%
Fat in dry matter ..	53·4%
pH	5·02

THE NON-FAT-LEAKING PROPERTY OF THE CHEESE.

Due to the fine state of division of the fat globules and their complete enclosure by the curd phase, there is a strong resistance against flowing of the fat at high temperatures. After prolonged holding, varying from 24 to 48 hours, at incubation temperatures varying from 100° to 130°F., there is negligible fat leakage from the cheese. Shape, condition, and appearance are maintained.

Normal cheddar cheese exudes fat profusely from 90°F. to 100°F., and at 120°F. becomes misshapen and finally a molten mass (see Plate 6).



A B C D

Plate 6.

Comparison of normal cheddar cheese and cheddar cheese from reconstituted milk under incubator conditions. A. Normal cheddar cheese before incubation. B. Cheddar cheese from reconstituted milk before incubation. C. Normal cheddar cheese after incubation at 120 deg. F for 18 hours. D. Cheddar cheese from reconstituted milk after incubation at 120 deg. F for 18 hours.

Comparative fat losses determined on midget (1 lb.) normal and experimental cheeses from 100 batches were:—

Temperature.	Incubation Period.	Percentage Fat Loss.	
		Cheese under Experiment.	Controls.
	Hours.		
105°F. ..	6	Nil	6
106°F. ..	24	0·5	10

Variations in Resistance to Fat Leakage.

Varying resistance to fat leakage was observed in some samples. To ascertain the extent of variation, fat losses from cubes of cheese (approximately $\frac{3}{4}$-inch sides) were compared from several batches, together with normal cheddar.

The cubes of cheese were placed on fat-absorbent filter paper in petri dishes, weighed, then held for 24 hours at 106°F., and the percentage fat loss determined. Percentage fat losses were recorded as follows:—

Experimental Cheese.	Normal Cheddar.
0·3	8·7
0·3	8·1
1·3	8·0
0·1	—
0·5	—
1·3	—
1·3	—

Differences in the degree of resistance to fat leakage do occur. However, the fat loss is slight in comparison with similar determinations on normal cheddar

Effect of Ripening on Resistance to Fat Leakage.

It was considered that the production of free fatty acids during ripening might affect the condition of the homogenized fat and cause a reduction in resistance to fat leakage. However, samples tested after six months' ripening showed no appreciable reduction. Comparative percentage fat losses determined on cubes of cheese cut from matured cheddar and experimental cheese (6 months' old) were:—

Experimental Cheese ..	0·5
Matured Cheddar	10·0

TABLE 2.

COMPARISON OF YIELDS OF EXPERIMENTAL CHEESE AND NORMAL CHEDDAR.

Experimental Cheese.							Normal Cheddar.						
Gallons of Milk.		Average Test.	Cheese Yield.	Lb. Cheese per lb. Butterfat.	Lb. Cheese per Gallon of Milk.	Fat Lost in Whey.	Overrun or Underrun.	Gallons of Milk.	Average Test.	Cheese Yield.	Lb. Cheese per lb. Butterfat.	Lb. Cheese per Gallon of Milk.	Fat Lost in Whey.	Overrun or Underrun.
			Lb.			%	Lb.			Lb.			%	Lb.
Group 1	634	4·0	685	2·71	1·08	0·10	51 over	2,318 ..	3·9	2,163	2·39	0·93	0·40	155 under
	573	3·5	597	2·97	1·04	0·06	24 over	2,137 ..	3·9	2,036	2·44	0·95	0·38	101 under
	422	3·6	439	2·87	1·04	0·08	17 over	2,459 ..	3·8	2,357	2·52	0·96	0·40	102 under
Group 2	782	3·6	775	2·75	0·99	0·10	7 under	780 ..	3·6	743	2·64	0·95	0·45	37 under
	737	3·6	747	2·82	1·01	0·12	10 over	755 ..	3·6	750	2·75	0·99	0·30	5 under
	790	3·6	768	2·70	0·97	0·07	22 under	794 ..	3·6	745	2·60	0·93	0·50	49 under
	774	3·6	726	2·61	0·97	0·08	48 under	773 ..	3·6	722	2·59	0·93	0·46	51 under
695		3·4	709	3·00	1·02	0·09	14 over	846 ..	3·4	822	2·85	0·97	0·35	24 under
800		3·8	841	2·76	1·05	0·10	41 over	775 ..	3·8	800	2·70	1·03	0·32	5 over
860		3·9	920	2·74	1·06	0·10	60 over	823 ..	3·7	800	2·62	0·97	0·30	23 under

As far as practicable, a representative bulk portion of the factory's milk supply was taken for yield comparisons. Casein contents were constant in both the experimental and control vats.

The results indicate the increased yield obtainable from reconstituted milk as compared with normal cheddar.

In the majority of batches, overruns were obtained from the homogenized milk as compared with underruns on the similar testing control batches. The district where the tests were carried out normally showed a lower casein content than surrounding districts, with lower yields. The reconstituted milk effected an appreciable improvement in cheese yield.

Other Factors Affecting Resistance to Fat Leakage.

Apart from the efficiency of homogenization and the method of manufacture, other factors affect fat leakage and require that the following precautions be taken:—

(1) Milk must be efficiently separated.
(2) Starter must be prepared in skim milk.
(3) Equipment such as coolers, vats, moulds, liners, &c., must be free of fat which has not been carefully homogenized.

YIELD OF CHEESE FROM THE RECONSTITUTED MILK.

Yields of cheese were somewhat higher than in the manufacture of normal cheddar. Typical results from the examination of 100 batches are given in Table 2.

In group No. 1, where farm conditions and pastures were normal, milk quality was affected by the warmer weather. In group No. 2, severe drought conditions operated and milk supplies were generally deficient in casein; consequently, yields were lower than normal.

Summarized, the yields were:—

	Average Yield per lb. of Butter Fat.	Average Yield per Gallon of Milk.
Cheese from reconstituted milk ..	2·79	1·02
Normal cheddar	2·61	0·96

Factors responsible for the increased yield include:—

(*a*) The reduced fat losses in manufacture.
(*b*) The reduced fat losses during storage.
(*c*) The higher moisture content of the cheese.

Cheese from reconstituted milk was manufactured as readily from milk of high fat content as from low testing milk, without a greasy texture or weak body.

FAT LOSS IN MANUFACTURE.

Fat losses were considerably reduced in the manufacture of cheese from reconstituted milk as compared with normal cheddar. Fat content of the whey as determined by the normal butyl alcohol Babcock test varied from 0·06 per cent. to 0·12 per cent.. Control vats showed from 0·30 per cent. to 0·40 per cent. fat in the whey. Whey separated by modern high-speed centrifugal separators shows approximately 0·05 per cent. fat. It would therefore appear uneconomical to separate the whey from reconstituted milk cheese.

Comparative figures for fat losses are:—

Fat Test of Milk.	Percentage Fat in Whey.		Percentage Fat Lost in Whey. (Of all Fat Received).	
	Experimental Cheese.	Normal Cheddar.	Experimental Cheese.	Normal Cheddar.
%				
3·8	0·06	0·30	1·57	7·89
4·0	0·08	0·40	2·0	10·0

MOISTURE CONTENT AND CONTROL.

The moisture content of cheese made from reconstituted milk tends to be higher than that of normal cheddar. In the initial trials it varied from 38 per cent. to 40 per cent., with difficulty in keeping some batches to 40 per cent. Control vats of normal cheddar cheese of the same day's make varied from 36 per cent. to 37 per cent. moisture. A slow "cook" at a high temperature (104-108°F.) assists in keeping moisture within the legal limit of 40 per cent.

Comparative moisture percentages in waxed cheese (21 days old) were as follows:—

Experimental Cheese.	Normal Cheddar Controls.
39·4	36·5
40·0	37·1
38·8	36·2
39·8	37·0
38·3	35·4

KEEPING QUALITY AND RIPENING.

The clarification of the milk during separation and the temperature maintained during milk separation and cream homogenization improve the cheesemaking quality of the reconstituted milk and the keeping quality of the cheese.

Homogenization, the use of an emulsifier, and the higher moisture content accelerated the ripening of the cheese.

Samples of the experimental cheese have been held for periods up to 6 months and compared with normal cheddar controls of the same day's make. Cheese from reconstituted milk ripened faster and in from four to six weeks had a flavour comparable with that of normal cheddar four months old.

There was a tendency to rapid drying-out if milk of a low bacteriological quality was used or manufacture was faulty.

DEFECTS AND THEIR CONTROL.

There were no indications that the cheese, if properly made from normal quality milk, should be inferior in keeping quality or more prone to defects than normal cheddar cheese.

Curd Flaking in Whey.

Normally the texture was very close and the whey clear. However, physical breakdown of the casein with consequent curd flaking in the whey sometimes occurred. Abnormal physical agitation through milk pumps and incomplete or faulty cheddaring produced an open crumbly curd and a finished product short and rough in texture. A rapid drying-out was typical of such cheese. Gentle handling of the curd, with a long and effective cheddaring, was necessary to rectify the defect.

High Acid Flavour.

The necessity for maintaining a comparatively low acid type of manufacture has been stressed. Acidity development typical of ordinary cheddar cheese manufacture results in a bleached, crumbly, high-acid reconstituted milk cheese. Controlled acidity in manufacture was essential to avoid the defect.

High Moisture Content.

A long "cook" at a temperature 2 to 4°F. above normal cheddar practice was essential for effective moisture control and firmness of body.

Rancidity.

Maintenance of a temperature of 160°F. throughout pasteurization, separation, homogenization, and reconstitution was necessary for complete destruction of lipolytic enzymes, thereby preventing the development of rancidity.

Weak or Soft Body.

Weak or soft body was a characteristic defect, and affected the keeping quality of the cheese. It may be due to the physical breakdown of casein in processing, but appeared to be more frequently due to ineffective moisture control by failure to "cook" long enough or at a sufficiently high temperature to dry out the curd effectively.

Rind Sweat.

With the development of a rind on the cheese after a period of approxi mately three weeks, a slight rind sweat may occur. The exact cause has not beer determined. However, the effect on resistance to fat leakage was negligible.

LAYOUT OF EQUIPMENT FOR MANUFACTURE.

The layout of equipment which was used for commercial manufacture is shown in Plates 7–9. This plant has been in operation at the Murgon factory of the South Burnett Co-operative Dairy Association.

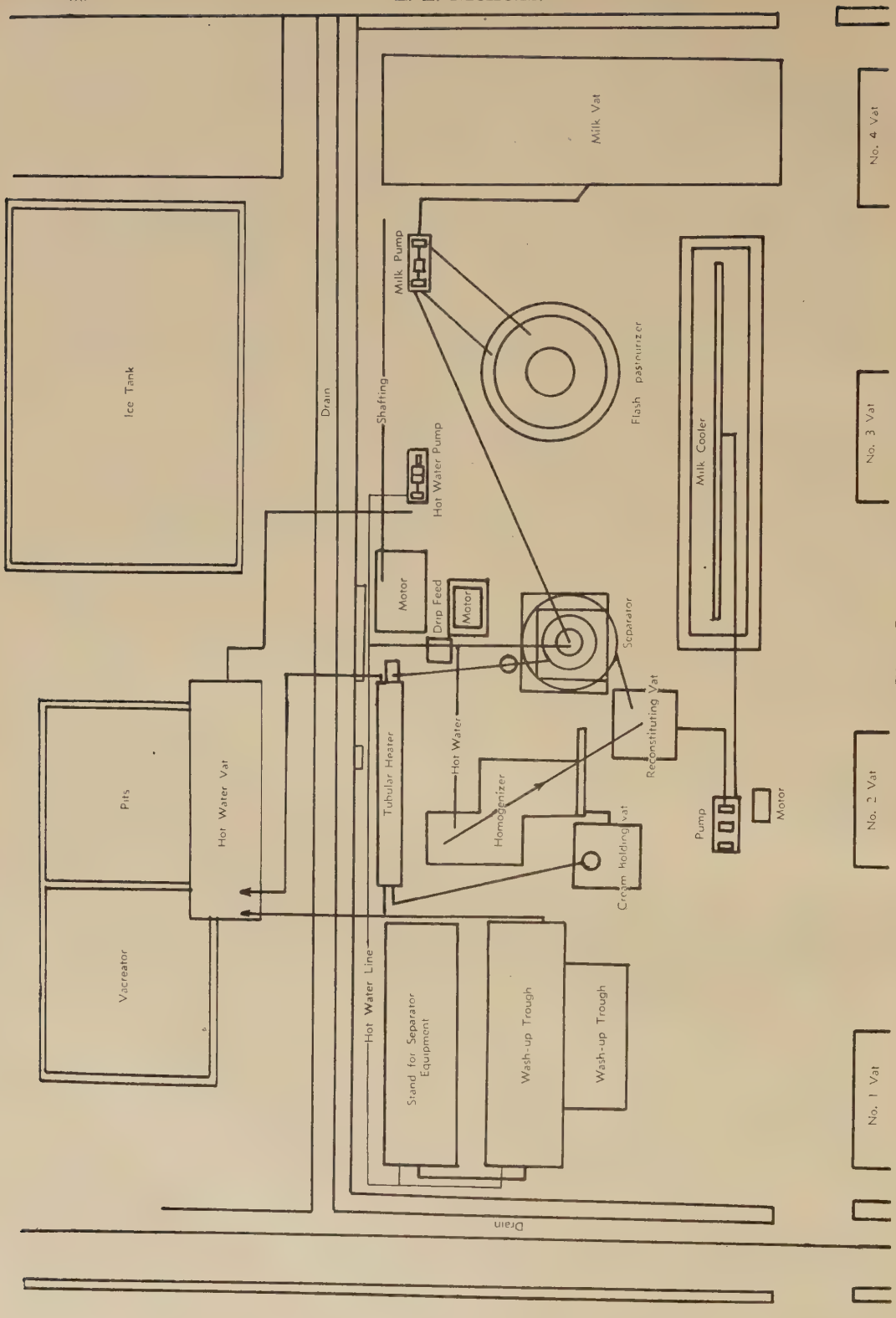


Plate 7.

Layout of equipment for manufacture of a non-fat-leaking cheese from reconstituted milk.

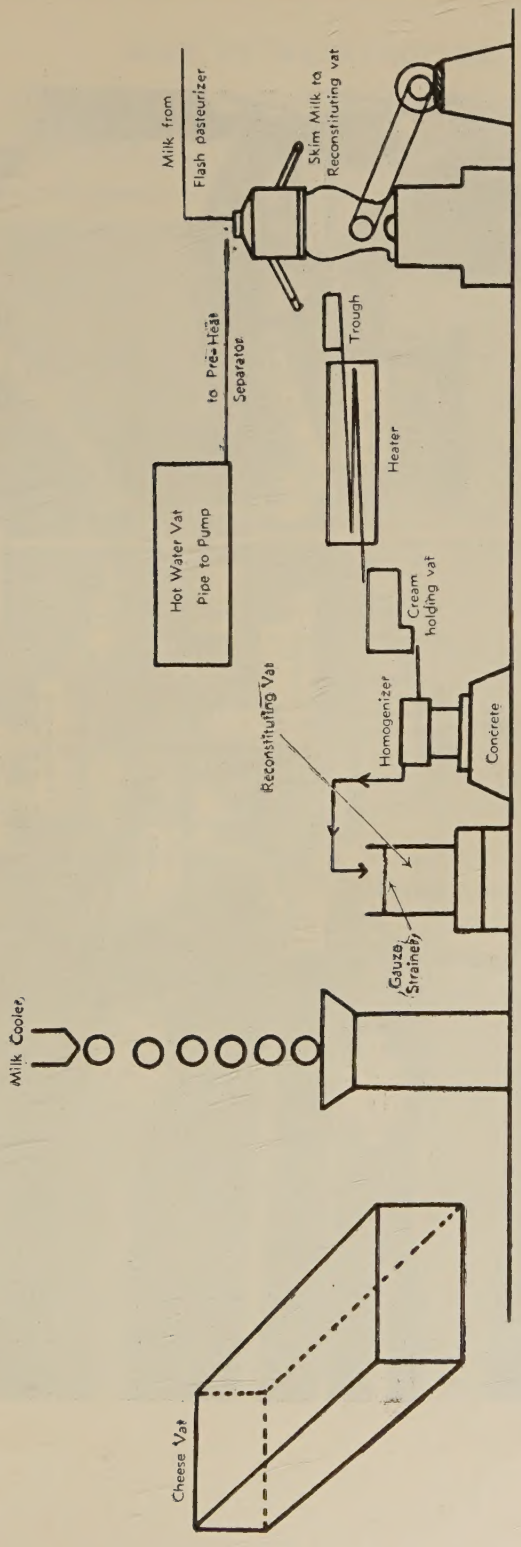


Plate 8.

Elevation of equipment for manufacture of a non-fat-leaking cheese from reconstituted milk.

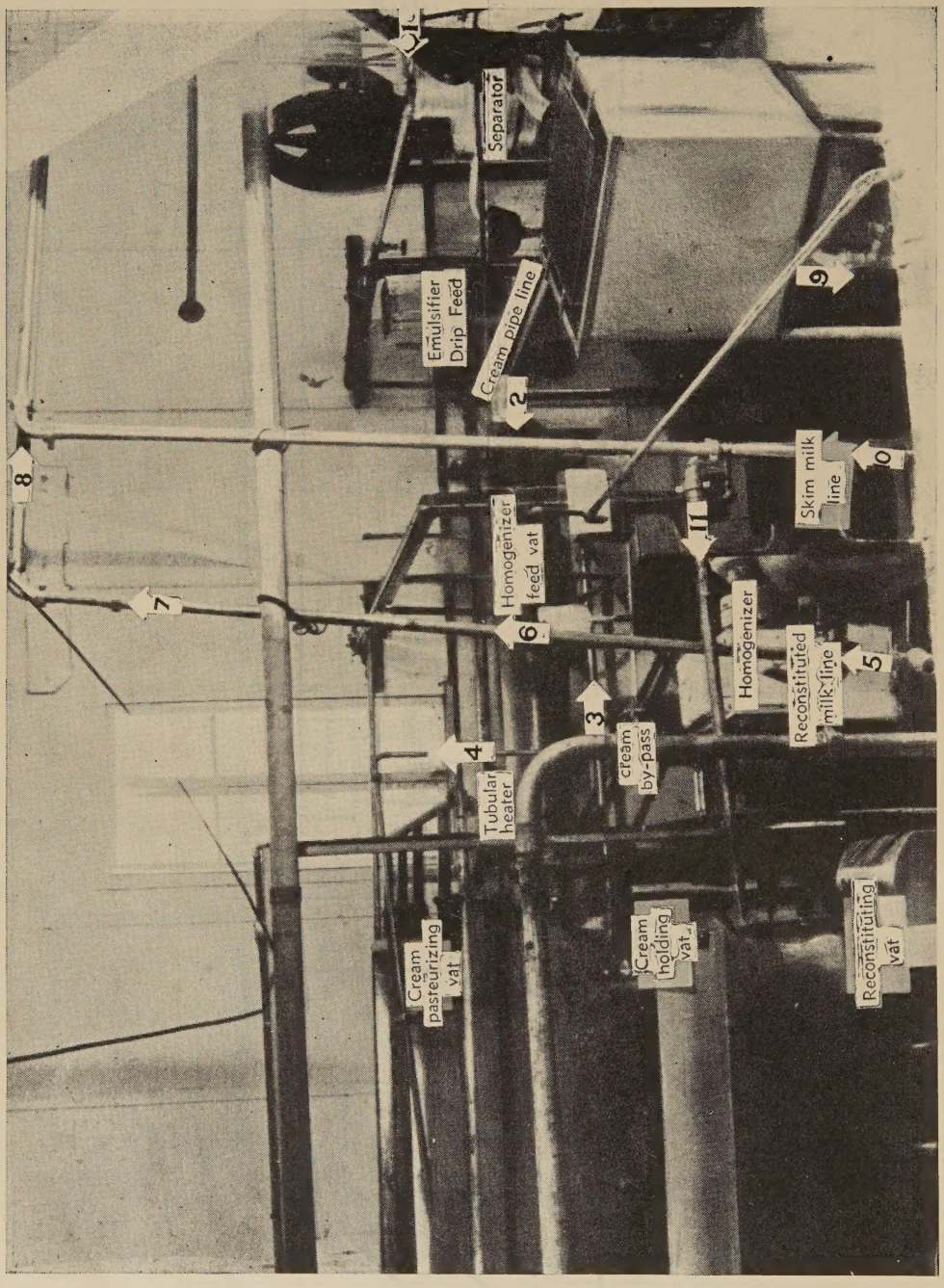


Plate 9.

Equipment used at the Murgon factory of the South Burnett Co-operative Dairy Association for the manufacture of a non-fat-leaking cheddar cheese from reconstituted milk.

COST OF MANUFACTURE.

It was estimated that the cost of making cheese from homogenized milk would not exceed ¼d. to ½d. per pound more than the cost of making ordinary cheddar cheese. The increased cost was offset by increased yields, reduced fat losses and rapid ripening.

With a separator and homogenizer of adequate capacity, little extra time, additional labour, or inconvenience is involved in manufacture as compared with normal cheddar cheese.

CONCLUSIONS.

(1) By separating whole milk, homogenizing the cream and reconstituting the milk, a type of cheddar cheese can be manufactured which will not exude fat at high atmospheric temperatures.

(2) Yields were higher than with normal cheddar because of the higher moisture content and the reduced loss of fat in the whey.

(3) Fat losses during manufacture and storage are minimized.

(4) When properly made the cheese is close in texture.

(5) The cheese is quick-maturing and has good keeping quality.

(6) The advantages of this kind of cheese held under adverse conditions in factory curing rooms, during transport in tropical or sub-tropical areas or in shops can be appreciated.

(7) The product offers possibilities for marketing as a rindless cheese which, when hygienically and attractively packed in cartons of, say, 1 lb. size, should prove palatable and popular with consumers in tropical and sub-tropical areas.

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